Year: 2011

Factors affecting cognitive development and plasticity in old age

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Factors Affecting Cognitive Development and Plasticity in Old Age

Thesis

presented to the Faculty of Arts

of

the University of Zurich

for the degree of Doctor of Philosophy

by

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of Treiten (BE)

Accepted in the spring semester 2011 on the

recommendation of Prof. Dr. M. Martin and Prof. Dr. F. Wilkening

Zurich, 2011

“It’s a fortunate person whose brain

Is trained early, again and again,

And who continues to use it

To be sure not to lose it,

So the brain, in old age, may not wane.” (Rosenzweig & Bennett, 1996, p. 63)

Acknowledgements

My heartfelt thanks to my supervisor, Prof. Dr. Mike Martin, whose encouragement, supervision and support from beginning to end enabled me to develop an understanding of the subject. Most of all, I appreciate his having given me the opportunity to realize my own ideas and to establish myself in a new field of research.

My thanks also go to my colleagues at the Department of Psychology, who so graciously invested their time and energy in helping with me this undertaking.
Furthermore, I owe my deepest gratitude to my family, who always had an open ear for me. They supported me in every conceivable way during the whole process of my thesis.

I am grateful to my little son Ben, who always welcomed me with a big smile after a hard day at work.

Finally, I would like to express my gratitude to the elderly who participated in my studies. They contributed much to the success of my thesis and are the main reason why I am now more than ever fascinated by this field of research.

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1 Introduction[1]

Although this thesis generally discusses various aspects of cognition and plasticity, its primary purpose is to identify factors positively influencing cognitive development and plasticity in healthy adults aged 60 and older. Furthermore, it considers ways in which cognitive plasticity affects age-associated decline in cognitive abilities, thereby achieving stability, an increase or a slowdown in decrease with regard to long-term cognitive performance. The introduction contains four sections: 1) a brief overview of the development of cognitive abilities in old age, 2) the concept of plasticity in old age, 3) various ways of achieving neurological as well as 4) behavioral plasticity in older adults.

The focus of this thesis is on education and training as possible methods to enhance plasticity. Four specific goals have been chosen based on the literature from current research in this field. The first goal is to outline the research on cognitive development in the oldest-old. Here emphasis has been placed on longitudinal studies, since they represent an important method for measuring change over a period of time, a task essential to plasticity research (chapter 3.1). The second goal is to examine extremely high education as a form of life-long cognitive training or cognitive stimulation, based on the hypothesis “use it or lose it”, which shows that a higher education can serve as protection against cognitive decline in old age (chapter 3.2). The third goal is to demonstrate the effect of different cognitive resources on dual-tasking using clinical and non-clinical samples (chapter 3.3). The fourth goal is to present the current literature on dual-task studies with suggestions for intervention. This information naturally provides a platform for the presentation of a new training design designed to maximize transfer and long-term effects (chapter 3.4).

[1] Parts of this chapter have been published in “Old Age in Europe” (Martin, Theill, & Schumacher, 2013)

1.1 Definition of Terms or Concepts

1.1.1 Cognitive Development in Old Age

Most cognitive abilities decline systematically across adulthood (Park et al., 1996). Various studies have demonstrated that in old age there is a general decline in speed of processing, working memory, cued and free recall and fluid intelligence. By contrast, performance on tests measuring crystallized intelligence remains stable or even increases over the life span (Horn & Cattell, 1967). However, longitudinal studies on cognitive aging have demonstrated that, despite this tendency of a decrease in cognitive abilities, some individuals maintain or even increase their cognitive abilities in old age. Schaie (1974), for example, proposes that most of the difference in the performance of cognitive abilities results from cohort differences rather than age differences. He even goes a step further by saying that "Presumed universal decline in adult intelligence is at best a methodological artifact" (Schaie, 1974, p. 802). This suggests that factors other than age should also be considered when looking at the development of cognitive abilities across the life span.

Baltes and Schaie (1976) point out that research on intellectual functioning in old age must carefully consider factors such as interindividual differences, multidimensionality, multidirectionality and the importance of generational differences. These might be the key factors in the study of abnormal, normal and extraordinary cognitive aging. As mentioned earlier, not all individuals demonstrate a decline in their cognitive abilities; some actually maintain or improve their performance even in old age. Interindividual differences should be considered in more depth in order to determine factors which cause positive aging. Two additional factors of cognitive development requiring further study are multidimensionality and multidirectionality. Cognition is composed of multiple abilities which demonstrate different developmental courses. Intelligence, for example, consists of fluid and crystallized intelligence. Whereas fluid intelligence decreases with age, crystallized intelligence normally increases. The development of cognitive abilities is also affected by historical as well as contextual influences. Such generational differences can be seen in the increase of intelligence over the years (Schaie, 2005). One final, yet crucial factor which is often completely neglected in the literature on cognitive aging is time. Certain effects might simply be the result of the amount of time spent on a task. Although we might expect a longer time spent on a task to be more beneficial, this might not be the case. The more time individuals spend utilizing an inefficient strategy, the less likely they might be to change to another more efficient one (cognitive rigidity). These factors suggest that age is often overrated as a predictor variable of cognitive development, and that there is much more variance in cognitive development than previous research has led us to believe.

Thus, as Baltes and Schaie (1976) mentioned, it is important to consider interindividual differences, multidimensionality, multidirectionality and the importance of generational differences to determine which factors positively influence cognitive development and plasticity. The most obvious way to examine such factors is to study interindividual differences in a large set of cognitive abilities over a long period of time and to analyze those individuals demonstrating positive cognitive development. However, the disadvantage of this method is that, even in a large sample, few individuals demonstrate cognitive growth or cognitive stability in old age. Therefore, another more economical approach might be to study a group of people who have a factor in common which is known to account for positive cognitive development and compare them with a heterogeneous group. In this way, it should be possible to get a direct and cross-sectional look at the influence of one target factor, for instance, education. However, when considering the influence of a particular factor on cognitive plasticity and the differences between two groups, longitudinal data should also be taken into consideration so that methodological artifacts can be minimized. These two aspects will be discussed in more detail at a later point in this thesis.

1.1.2 Cognitive Plasticity

As previously mentioned, there are various factors demonstrating that cognitive development is characterized by continuous alteration, in other words, cognitive plasticity (Baltes & Labouvie, 1973). Willis, Schaie, and Martin (2009) define cognitive plasticity as an individual’s latent cognitive potential or the individual’s cognitive capacity under certain specified conditions. Since there is a close relationship between neuronal activation and cognition for certain cognitive abilities, cognitive plasticity should be observable in both neuronal as well as behavioral data (a further aspect would be socio-cultural plasticity). However, the exact relationship between them is still unclear. Some researchers have demonstrated that in the elderly there are only small or even negative effects between cognitive performance and the reductions in cortical volume (Rodrigue & Raz, 2004). According to Stern (2002), for instance, cognitive plasticity can exist despite the fact that neuronal plasticity has been compromised *(cognitive reserve)*.

In contrast to the passive models of brain reserve, which see reserve as the result of brain size and synapses, the theory of active cognitive reserve states that the brain actively copes with or compensates for pathology. Concerning plasticity this means that the brain is able to utilize brain networks more efficiently or acquire new compensatory brain networks. This phenomenon has been observed in individuals with higher levels of intelligence and educational and occupational achievement. Whereas people with lower intelligence demonstrate functional deficits after a certain type of brain damage, people in the same situation with a higher level of intelligence can maintain their performance level. This concept of cognitive reserve can be transferred to non-pathological aging. Since the brain is subject to various age-associated decomposition processes, an active lifestyle can build up cognitive reserve, which allows long-term plasticity even in old age. Although the exact relationship between behavioral and neuronal plasticity is not fully understood, neuronal plasticity, as seen in the cognitive reserve theory, plays a crucial role in the understanding of cognitive plasticity (Stern, 2002).

However promising the theory of cognitive reserve sounds, further aspects must be considered when examining the relationship between factors accounting for cognitive reserve and brain plasticity. It is not clear whether intelligence, education level, occupational achievement enhance cognitive reserve. It might be possible that cognitive flexibility is an initial state which manifests itself in high intelligence, advanced education and occupational achievement. This would mean that these factors are a mere product of cognitive flexibility or cognitive reserve rather than the source. Therefore, longitudinal research is needed to further investigate the factors accounting for cognitive reserve.

1.1.3 Neuronal Level of Cognitive Plasticity

Hebb (1949) was one of the first researchers to postulate the hypothesis of use-induced plasticity of the nervous system. Although his idea of synaptic plasticity seemed plausible, he could not prove it experimentally (Rosenzweig & Bennett, 1996). Later on, other researchers were able to demonstrate through animal research that training and experience can lead to plastic changes in cerebral neurochemistry and neuroanatomy. Rosenzweig, Krech, and Bennett (1961) trained rats to solve a variety of problems. Their results provided evidence that a demanding environment can lead to structural changes in the brain. These findings have been observed in other species such as mice, gerbils, ground squirrels, cats and monkeys (Renner & Rosenzweig, 1987). Food-storing birds, for example, have significantly larger hippocampal formations than related species which do not store food (Krebs, Sherry, Healy, & Perry, 1989; Sherry, Vaccarino, Buckenham, & Herz, 1989). This finding is not only species-dependent, but also experience-dependent, which means that the hippocampus of the same species varies according to their exposure to experience. Thus, young as well as older hand-raised birds do not show the typical hippocampal formation as their older wild colleagues. Even more interesting concerning plasticity in old age, these animals (even when they are older) still demonstrate an increase in hippocampal size when they are trained or live in an enriched environment (Rosenzweig & Bennett, 1996).

The same change of neurochemistry and neuroanatomy has been observed in humans exposed to a stimulating environment or having undergone training. Maguire et al. (2000), for example, used magnetic resonance imaging (MRI) to compare the brains of 16 London taxi drivers with those of 50 control subjects who were non-taxi driver (all between the ages of 32 and 62 years). The data demonstrated that there were structural differences between the brains of the taxi drivers and the control subjects. While taxi drivers had significantly larger posterior hippocampi, the control subjects had a larger anterior hippocampal region. Since the posterior hippocampus is thought to store spatial representations of the environment, these findings are consistent with the idea that an enriched environment can lead to neuronal plasticity. Similar structural changes take place when individuals are given motor, aerobic or cognitive training.

Draganski et al. (2004) trained 12 people (average age 22 years) in juggling over a period of three months. The training group as well as the control group were scanned at the beginning, directly after the training and three months after the training was terminated (MRI). The training group demonstrated a significant transient bilateral expansion in gray matter in the mid-temporal area and in the left posterior intraparietal sulcus between the first and the second scan, which was not found in the control group. In the third scan these differences between training and control group had started to fade, which means that the training gains were disappearing. Four years later, the same research group conducted the same study with healthy elderly individuals (average age 60 years) to measure if the plasticity of the aging brain remains into old age (Boyke, Driemeyer, Gaser, Buchel, & May, 2008). Although the older participants did not show the same training benefit on the behavioral level, they had similar training effects, though smaller, on the structural level.

Not only motor training but also aerobic training has a beneficial effect on brain plasticity in old age. Colcombe et al. (2006) demonstrated that 60 to 79-year-olds who attended an aerobic exercise training three times a week over a period of six months significantly increased the gray and white matter of their prefrontal and temporal cortices. Interestingly, these are regions often reported to show substantial age-related deterioration. These findings indicate that physical training not only helps to maintain or slow down age-related losses in brain structure, but also that brain structures can be rebuilt to a certain extent.

Given these results from motor and aerobic training, it seems likely that cognitive training should also lead to brain plasticity, since it stimulates brain through activation of neural networks. However, there have only been a few studies which actually focused on the relationship between cognitive training and changes in brain function and brain anatomy (cf. Erickson & Kramer, 2009; Nyberg et al., 2003). Erickson and Kramer (2009) were able to demonstrate that performance improvement in dual-task training was accompanied by an increase in hemispheric asymmetry and a reduction in age differences in ventral and dorsal prefrontal activation. As in the previously described study of Colcombe et al. (2006), their study found beneficial effects in areas commonly associated with the largest age-related atrophy. According to the authors' argumentation, these results provide further evidence for plasticity in old age.

Although all of the studies mentioned indicate that neuronal plasticity exists across the whole lifespan, they also point out that the factors which lead to neuronal plasticity differ according to the stage of the individual's development. For instance, Rosenzweig and Bennett (1996), in their concluding commentary on brain plasticity, state: "Thus, whether the adult brain remains plastic to a particular kind of experience depends on the brain region, the kind of experience and perhaps also on special circumstances that enhance or impair plasticity" (p. 59). Furthermore, they say "but we should add to that the fact that use and experience are especially effective early in life and they set the basis for later use and maintenance of the brain and of ability" (Rosenzweig & Bennett, 1996, p. 63).

The previously mentioned literature concerning brain plasticity in old age raises many questions. Although Rosenzweig and Bennett (1996) admit that factors such as brain region, kind of experience and special circumstances affect cognitive plasticity, they clearly state that use-induced plasticity is especially effective when a person is young. However, it is not clear what they understand by effectiveness of experience. If youth is commonly associated with cognitive growth, then it is not surprising that a stimulating environment causes more change in a young brain than in an old one. However, since old age is accompanied by a decline in most of the cognitive abilities, stability or even a small increase might be exceedingly important. Hence, the increase in brain plasticity in elderly might not be as obvious as in younger people but, proportional to the average cognitive development in old age, it is more effective.

This leads to a further point; namely the process of cognitive plasticity. If brain plasticity decreases with increasing age, it is of major interest to determine exactly how brain plasticity develops across the lifespan. This thesis focuses on development in the old and oldest-old. It might be that the decrease of brain plasticity proceeds linearly, meaning that brain plasticity decreases every year by the same amount. However it might also be possible that the level of brain plasticity stagnates after the age of 80 or that, after a certain age, the brain loses its plastic characteristic. Therefore, more longitudinal research on the brain development of the oldest-olds is needed to find out the limitations but also the extent of cognitive plasticity.

1.1.4 Behavioral Level of Cognitive Plasticity

Commonly, the behavioral level of cognitive plasticity is understood to be the behavioral changes, seen in cognitive abilities, resulting from a stimulating environment or stimulating training. To describe the nature of behavioral cognitive plasticity, Baltes (1987) proposed three different aspects of plasticity: baseline performance, baseline reserve capacity and developmental reserve capacity. Baseline performance describes the initial level of performance in a task without any external influences through training or any other facilities. Baseline reserve capacity designates an individual’s maximum performance level, calling on all available resources. If a person’s baseline reserve capacity is strengthened through intervention, it changes to developmental reserve capacity.

Different methods have been developed to measure the previously mentioned aspects of plasticity. Baseline performance of an individual, for example, is assessed by testing cognitive abilities using various cognitive tests. To measure baseline reserve capacity Kliegl, Smith, and Baltes (1989) introduced the testing-the-limits methodology. Since developmental reserve capacity describes the capacity strengthened through intervention, the most commonly used method for this is training. Following is a description of the methodology of testing-the-limits as well as different training approaches.

The idea behind the testing-the-limits approach is to train people until they achieve their maximum performance level in a certain task. Training individuals to their maximum performance limits makes it possible to exclude unintentional factors such as differences in task familiarity or intellectual abilities. Furthermore, it nicely demonstrates an individual’s developmental potential in the task being trained. In this way, performance differences in a task can be more certainly attributed to age than performance differences in a task measuring the average baseline performance level. A method often used to train a person’s maximum performance level is a mnemonic technique called the Method of Loci, which requires mental imagination to encode and retrieve lists of words from memory in serial order (cf. Kray & Lindenberger, 2007). Baltes and Kliegel (1992) , for example, compared the training benefits of 20 to 30-year-olds with those of 66 to 80-year-olds after extensive word training (Method of Loci). Their results demonstrated that there is a sizable reserve capacity in old age.

However, despite this result, Baltes and Kliegl (1992) argue that a robust (something akin to irreversible) negative-age effect is present in certain factors and processes of the mind associated with the use of the method of loci. Although these results indicate that plasticity exists over the lifespan, they also point out, as do the previously mentioned neuroanatomical studies, that the amount of plasticity decreases with increasing age.

Developmental reserve capacity can be strengthened by interventions administered intentionally, such as trainings, or interventions which happen unintentionally, such as a stimulating environment. The environmental factors known to enhance plasticity are formal and informal education, leisure pursuits, intellectual engagement and expertise in different skill domains (Kramer et al., 2004).

It is not new that education might influence cognitive development across the lifespan. Already back in the Ancient Greece, it was assumed that education had a beneficial effect on old age. As Aristotle once said “Education is the best provision for old age” (Aristotle 384-322 BC). In their review, Kramer, Bherer, Colcombe, Dong, and Greenough (2004) summarized the most prominent articles investigating education as a predictor of cognitive vitality. They suggest that education can function as an effective impetus for cognitive vitality in late adulthood. However, they indicate that different other variables influence the relation between education and cognitive abilities in old age. Hultsch, Hertzog, Small, and Dixon (1999) looked at the relationship between the change in different cognitive variables and intellectually-related activities. They found a significant relationship indicating that intellectually-engaging activities can help to maintain cognitive abilities in old age. Although these results are promising given the beneficial effect of an intellectually-active lifestyle, the causal direction does not become clear between an intellectually-active lifestyle and cognitive high-ability individuals. These results and other findings in the cognitive reserve literature (Stern, 2002) indicate that education as well as intellectually-related activities account for cognitive plasticity and therefore serve to shield individuals from decline. However, the exact circumstances under which education and intellectual engagement can lead to maximum plasticity have not yet been determined.

Another way in which an individual’s developmental reserve capacity may be enhanced is through training. Training can be characterized as having been successful when there are large training gains and broad and long-lasting transfer effects. Following is a discussion of these training characteristics as well as methods which help maximize the training outcome.

Training gains in the trained task can be seen by tracking the performance over the different training sessions. Buschkuehl et al. (2008), for example, demonstrated that elderly participants improved their performance up to 62% in a working memory task over the period of twelve training sessions. Many other studies provided similar results, indicating that older adults significantly improved their performance over training periods lasting up to 45 training sessions (cf. Baltes & Kliegl, 1992; S. C. Li et al., 2008). Although these findings indicate that elderly people certainly benefit from cognitive training, the number of training sessions needed or the optimal duration of training sessions and intervals is still unknown. Ericsson, Chase, and Faloon’s study (1980) required a college student with average memory abilities and average intelligence to practice memorizing digits for over 230 hours. In the first session, the student reproduced seven digits; by the last session, he could remember up to 79 digits. These and other findings indicate that there are no limits to memory performance when training has taken place (Baltes & Kliegl, 1992; S. C. Li et al., 2008). Therefore, there is no standard for choosing the optimal number of training sessions for a particular type of training. The same applies to the duration and intervals of the training sessions. In the literature, the duration of training sessions varies from about half an hour to three hours; training intervals from daily training to one training session per week (S. C. Li et al., 2008; Verhaeghen, Marcoen, & Goossens, 1992; Zehnder, Martin, Altgassen, & Clare, 2009). Since most of the trainings demonstrate training gains in the task trained regardless of the number of sessions, the duration or intervals of the training sessions, these training characteristics might not be important for a significant training gain. However, they are currently often discussed with regard to the amount of influence they may have on transfer and long-term effects.

In the training studied, the training effects seen in cognitive tasks other than those being trained are referred to as transfer effects. These are divided into two groups: near and far transfer. According to Willis, Schaie, and Martin (2009), near transfer focuses on demonstration of training effects to one or more indicators of the ability trained. Far transfer, on the other hand, demonstrates training effects on cognitive processes or abilities that are conceptually and empirically distinct from the cognitive target of training. Barnett and Ceci (2002) provide an even more detailed definition. They established a framework with nine relevant dimensions, including content as well as context information, which helps to classify the transfer effects in near and far transfer. Whereas almost all training studies find near transfer effects, only a few demonstrate far transfer effects. Although all training studies try to train a particular cognitive ability, the ability they actually train is not the same in all studies. Davidson, Zacks, and Williams (2003), for example, conducted a training study with the goal of enhancing inhibition, Dahlin, Nyberg, Bäckmann, and Stigsdotter Nelly (2008) executive function and Buschkuehl et al. (2008) working memory. The following section will primarily focus on one cognitive ability to be enhanced in the training condition, namely the working memory, as well as on near and far transfer effects.

There are various ways to train and test working memory. S. C. Li et al. (2008) trained participants in a special 2-back task and in a more demanding mental shifting condition of the same task. They found training gains in the trained task as well as near transfer effects to a more demanding special and numerical n-back task. Although these transfer effects were maintained over three months, neither short- nor long-term far transfer effects have been observed. Buschkuehl et al. (2008) trained elderly individuals in three different working memory tasks. Participants were either asked to reproduce a previously shown sequence of four squares, two animals or eight animals. The results demonstrated significant training gains in the trained task and near transfer tasks, whereas only moderate group difference effects existed between the training and the control group in the far transfer tasks. However, one year after training completion, the two groups differed neither in the near nor in the far transfer tasks. These working memory training studies found training gains and near transfer effects and to a certain extent even far transfer effects, whereas these mostly disappeared in the follow-up test. The only study which has demonstrated broad far transfer effects is the working memory training study of Borella, Carretti, Riboldi, and De Beni (2010). They found near transfer effects in a forward and backward digit span task and in a visuo-spatial working memory task and far transfer effects in fluid intelligence, inhibition and speed of processing. In the follow-up test eight months later, long-term effects could be seen only in fluid intelligence and speed of processing. Since the training of Borella et al. (2010) had the fewest training sessions (three compared to 23 (Buschkuehl et al. (2008) and 45 S. C. Li et al. (2008)) and the broadest transfer effects, it seems that the number of training sessions is not relevant to obtain positive transfer effects. In addition, neither training duration nor frequency played a major role in the effectiveness of the three different trainings. Since the different training characteristics (session number, duration, training interval) do not appear to be the most important factors for training success and maintenance, it might be that the training procedure or the combination of procedure and certain training characteristics influence the training outcome most.

High-level training procedures are defined as either process-based or strategy-based, whereas low level training procedures are task-specific or adaptive (cf. Baltes & Kliegl, 1992; S. C. Li et al., 2008). Working memory training is always process-based, which means that participants are not instructed to utilize a certain strategy. In the literature, advantages as well as disadvantages are found for both procedures. On the one hand, strategy-based training can improve memory performance for a given type of stimuli to a very impressive extent. On the other hand, the effects remain very task, context and stimuli-specific (Buschkuehl et al., 2008). In opposition to this, strategy-based training often has few if any transfer effects to other tasks, but can push individuals to their maximum performance levels and is therefore extremely motivating. Furthermore, process-based and strategy-based training can also be either adaptive or task-specific (cf. Borella et al., 2010). The training is task-specific if the task as well as the level of difficulty of the training remains the same throughout the whole training, whereas it is an adaptive training if the level of difficulty is adjusted to the person's training progress. Borella et al. argued that in their study the combination of an adaptive repetitive procedure might have accounted for such broad transfer effects. However, more research is needed to determine which factors influence the training gains and transfer effects of training most.

In addition to the near and far transfer previously mentioned, there is a further type of transfer, namely the transfer to another modality. This means that, in cognitive research, far transfer typically consists of training effects on cognitive processes or abilities which are conceptually and empirically distinct from the cognitive target of training (cf. Willis et al., 2009). However, training effects on cognitive processes or abilities can occur even when a person is trained to do another task, such as an aerobic task or some other non-cognitive task.

The study of the relationship between cognitive and physical health resulted from the observation that physically fit elderly people outperformed their sedentary colleagues in several cognitive tests (Dustman, Emmerson, & Shearer, 1994). This relationship was later investigated more systematically and in more detail in various studies between 1966 and 2001, a summary of which has been provided by Colcombe and Kramer (2003). Their meta-analysis demonstrated that the exercise groups performed significantly better in tasks of executive processes, cognitive control, visuospatial information processing and speed of processing. The effect of exercises on executive processes was significantly higher than the effect on any other task. Furthermore, they found that training characteristics such as type of intervention, session number and duration influenced the magnitude of the training effect.

Since physical training positively influences cognitive abilities, it may be assumed that there is a close relation between motor function and cognition. According to Huxhold, Li, Schmiedek, and Lindenberger (2006) dual-task can lead to stability or improve performance if both tasks performed require only a few resources. However if motor or cognitive load exceeds a certain aspiration level, cognitive and motor performance decreases under dual-task conditions. So far, little is known about the interplay of physical and cognitive function and the factors which influence them. It is of major interest to discover in what way a systematical improvement in one modality affects performance in some other modality as well as the performance of the combined tasks.

Training research focusing on the behavioral level of cognitive plasticity has demonstrated that there are various factors and methods which may enhance a person’s baseline and developmental reserve capacity. In addition to stimulating environmental factors, such as high education and intellectual engagement, training can contribute to an increase in cognitive plasticity. The current training research indicates that cognitive training can improve the performance of the trained task as well as similar tasks. More research is needed to determine to what extent these effects can be found in tasks which are conceptually and empirically different from the trained task. Furthermore, physical training studies have demonstrated that near and far transfer effects occur not only in the same modality, but also in a different modality, such as from physical to cognitive.

These findings suggest that a stimulating environment as well as training have positive effects on cognitive plasticity. This is obviously the case since both stimulate cognition in various ways. A further attempt therefore might be to include the positive characteristics of a stimulating environment in the training condition. This could be achieved by creating an artificially-stimulating training environment similar to everyday life situations, assessing single- and multi-task performances, and using different difficulty levels of all of the component tasks (cf. K. Z. H. Li et al., 2005). As will be described later on, exposure to a multitasking setting has different advantages. First of all, the more similar the training situation is to everyday life, the greater the chance that the training will have a beneficial effect on everyday life. Secondly, multitasking requires more resources, which in turn has a positive effect on high order processes. Thirdly, it is assumed that multitasking of different modalities causes greater cortical stimulation and therefore a larger and longer lasting training effect will occur.

The studies mentioned above indicate that cognitive plasticity exists on the neuronal and behavioral levels across the lifespan. Factors which influence plasticity are, amongst other things, education, intellectual engagement and cognitive and physical training. It has been demonstrated that they help to moderate age as well as time-associated declines in cognitive development. However, the exact relationship between these factors and cognitive plasticity is not fully understood. Interindividual differences, for example, have been neglected in almost all studies although they are essential to determining further characteristics of cognitive plasticity. Furthermore, there is an obvious need to analyze the influence of various stimulating environmental factors, contextual information and their interaction on cognitive plasticity. The literature on physical and cognitive training has shown that both kinds of training influence cognitive development positively. A further step is to look at the interplay of cognitive and physical functioning. These considerations have resulted in the following research questions.

2 Aims and Research Questions

The general goal of this thesis is to determine and investigate factors positively influencing cognitive development and plasticity in old age. This is achieved by using a multi-method approach analyzing cross-sectional and longitudinal data as well as by considering newly-collected data from experimental studies. More specifically, it aims, first of all, to provide a better understanding of cognitive development and plasticity in the oldest-old by analyzing existing longitudinal studies investigating cognition across old age. Second, it investigates the influence of a stimulating environment on cognition in old age, focusing primarily on higher education. Third, it examines and conceptualizes the possibilities provided by combining physical and cognitive training with regard to increasing resources and improving cognitive plasticity.

2.1 Longitudinal Studies on The Oldest-old

Although there have been several longitudinal studies investigating older people, only a few have concentrated on the oldest-old. It is essential to examine individuals aged 80 and older in order to determine factors which have an impact on healthy cognitive aging over the whole lifespan. Successfully aging people often demonstrate that they have adapted well to personal and environmental changes. This might be manifested in neuronal or behavioral plasticity. In order to explore this possibility, longitudinal data was collected on individuals aged 80 and older and will be analyzed concentrating on factors which account for a positive cognitive development in old age at a later date. What opportunities and challenges do such longitudinal studies provide?

This first research question is explored by analyzing all longitudinal studies lasting at least five years, having a minimum of two data waves and involving participants aged 80 years and older. Following is a discussion of the methodological challenges to be considered when analyzing the data for factors positively influencing cognitive plasticity.

2.2 An Intellectually-stimulating Environment and Cognitive Aging

The literature on cognitive plasticity suggests that a stimulating environment positively affects cognitive development in old age. However, little is known about the underlying factors of education and their influence on cognitive aging in older adults at a high level of cognitive functioning. This means it is important to determine whether it is formal education, personal characteristics, involvement in a demanding job, or working after retirement which positively affects cognitive development and plasticity in old age. What influence does an intellectually stimulating environment have on cognitive aging? The second aim of this study, therefore, is to demonstrate the relationship of extremely high education and its underlying factors to cognitive aging by analyzing the data of the first wave of one longitudinal study. In 2006, data was collected in the field of cognition, cognitive engagement, personality, subjective well-being and socio-economic status from 86 university professors between the age of 64 and 92 years. The results of the cognitive tests for this high education sample will be compared to a normally educated sample in chapter four of this thesis. A cross sectional design will be used to investigate the extent to which cognitive engagement and education may affect age-related differences in cognitive performance in old age.

2.3. Dual-Task Costs as Function of Cognitive Status

In order to manage daily life, individuals must be able to perform tasks that simultaneously integrate multiple elementary cognitive abilities. The literature on multitasking has demonstrated that with increasing age this ability decreases. Even the combination of a highly motorized task such as walking with a cognitive task can lead to a performance decrease in one or both tasks. Although this thesis concentrates on healthy cognitive aging, it is of major interest to investigate dual-task performance in relation to cognitive status. In this way, it should be possible to determine how losses in cognitive resources are compensated in dual-task situations. What influence does cognitive status have on dual-tasking? Thus, the third aim of this research is to examine at dual and single-task performance as a function of cognitive status. Therefore, a large sample of cognitively healthy and cognitively impaired elderly are compared concerning gait velocity, semantic memory and working memory in dual and single-task condition. It is hypothesized that dual-task costs are greater in individuals with lower cognitive abilities, especially in relation to the cognitive task.

2.4 Dual-Task Performances and Their Impact on Cognitive Plasticity in Old Age

As mentioned above, various studies have demonstrated that physical training enhances cognitive performance. Therefore, it can be assumed that there is a close relation between physical functioning and cognition. However, it is not clear how these two functions are related. Although physical training enhances cognitive performance, the opposite does not seem to be the case. Furthermore, under dual-task conditions the simultaneous performance of a physical and cognitive task often leads to a decrease in the overall performance, especially in older individuals. It appears that, if fewer resources are available, both physical and cognitive functions compete for these remaining resources. What then are the mechanisms underlying dual-task performances in old adults and how could they positively affect cognitive plasticity in old age?

The aim of this third research question is to provide an overview of the current literature on the interplay between cognitive and motor functioning and to demonstrate possibilities for intervention. It is hypothesized that training physical and cognitive functioning simultaneously will improve both physical and cognitive performance and the combination of them by enhancing the available resources. This enhancement of resources, namely the developmental reserve capacity, would be a further indication of cognitive plasticity in old age

3 EMPIRICAL STUDIES

In the following section, four studies are presented which address the research questions in consecutive order. The first study gives an overview of cognitive plasticity in the oldest-old. This is followed by an experimental study about the relation of cognition and education in a sample of highly functioning old adults, a study on the relation between cognitive status and dual-tasking and finally a conceptual chapter on research of the interplay between cognitive and motor functioning. The results and conclusion of each study are presented at the end of each chapter. The thesis concludes with a summary and overall discussion.

3.1 Study 1: Psychologie der Hochaltrigkeit: Kognitive Entwicklung im hohen Alter[2]

3.1.1 Einleitung

In der Entwicklungspsychologie der Lebensspanne (Baltes, 1990; Martin & Kliegel, 2008) wird die Gleichwertigkeit aller Lebensphasen für die lebenslange Entwicklung betont. Während es für die meisten Altersbereiche Erkenntnisse über Entwicklungs- und Adaptationsprozesse und zur kognitiven Entwicklung gibt, ist die Psychologie des sehr hohen Alters aufgrund der bisher nur selten verfügbaren Längsschnittdaten stärker in der Charakterisierung von Eigenschaften von Personen als in der Charakterisierung von Entwicklungsprozessen. Wir gehen daher im vorliegenden Kapitel auf der Basis einer kurzen Geschichte der Psychologie des sehr hohen Alters zunächst der Frage nach, welche Längsschnittdaten international zu Prozessen kognitiver Entwicklung im sehr hohen Alter

[2] A similar version of this chapter has been published in “Hochaltrigkeit: Herausforderung für persönliche Lebensführung und biopsychosoziale Arbeit” (Schumacher & Martin, 2011)

vorliegen. Anhand von drei beispielhaft ausgewählten Studien wird die Befundlage beschrieben. Schliesslich gehen wir auf die besonderen methodischen und theoretischen Herausforderungen in der längsschnittlichen Erforschung des sehr hohen Alters ein und skizzieren einen konzeptionellen Rahmen für die zukünftige Erforschung von Entwicklungsprozessen im sehr hohen Alter.

3.1.2 Tradition der Psychologie der Hochaltrigkeit

Die Psychologie der Hochaltrigkeit bezieht sich auf die altersbezogenen Veränderungen psychologischer Kompetenzen von Personen oberhalb der mittleren Lebenserwartung, also etwa ab dem 85. Lebensjahr. Für diesen Altersbereich hat sich in Abgrenzung vom Berufsalter oder „Zweiten Alter" und dem jungen (Nachberufs-) Alter zwischen 65 und 85 Jahren oder „Dritten Alter" in der Literatur auch die Bezeichnung „altes Alter", „sehr hohes Alter" oder „Viertes Lebensalter" (Baltes, 1997) eingebürgert. Gerade in den Untersuchungen zum Vierten Alter wird hervorgehoben, dass es im Vergleich zum jungen Alter mit einem deutlich erhöhten Risiko für Morbidität und Mortalität einhergeht. Dies ist aus zwei Hauptgründen problematisch: Erstens ist es per Definition klar, dass zwischen dem Überschreiten der mittleren Lebenserwartung, also zum Zeitpunkt zu dem die Hälfte einer Geburtskohorte verstorben ist, und dem maximalen Alter von bisher 122 Jahren ein kürzerer Zeitraum liegt als zwischen Geburt und mittlerer Lebenserwartung. Dass daher im Vierten Alter das Sterblichkeitsrisiko grösser ist, ergibt sich aus der Altersdefinition. Zweitens kann das Vierte Alter nicht mit Gebrechlichkeit gleichgesetzt werden, da es erhebliche Unterschiede innerhalb dieser Altersgruppe gibt und nicht alle Personen in gleicher Weise beeinträchtigt sind, wie das der Begriff vermuten lassen könnte. Gebräuchlicher ist es in diesem Zusammenhang mittlerweile ohne Bezeichnung einer Altersgrenze vom funktionalen Alter zu sprechen. Insgesamt kann als Gegenstand der Entwicklungspsychologie der Hochaltrigkeit die Beschreibung und Erklärung von Veränderungen psychologischer Ressourcen im Alter ab 85 Jahren angesehen werden.

Konsultiert man die englischsprachige Fachliteratur, sind auch hier mit Hochaltrigen „the oldest old“ und Personen ab dem 85. Lebensjahr gemeint. Diese Altersgrenze scheint nicht nur kulturabhängig sondern auch zeitabhängig zu sein. Wie die bisherige Entwicklung der mittleren Lebenserwartung seit 1840 gezeigt hat, werden die Menschen weltweit im Durchschnitt immer älter. Mit dieser Verschiebung der Lebenserwartung verlängern sich auch die verschiedenen Lebensabschnitte, sodass sich in Zukunft die Psychologie der Hochaltrigkeit mit der Erforschung noch älterer Personen beschäftigen wird (vgl. Perls, 1995; Suzman, 1995; Wahl & Rott, 2002).

3.1.3 Ursprünge der psychologischen Hochaltrigkeitsforschung

Obwohl schon 1920 die Psychologie des Alters aufkam (Hall, 1922), ist die Psychologie der Hochaltrigkeit eher etwas Neues. Die Betrachtungsweise des hohen Alters lehnte sich zunächst stark an die biologischen, physiologischen, medizinischen, historischen, literarischen und philosophischen Aspekte des Alterns an (Birren & Birren, 1990). Hall (1922) beispielsweise konzentrierte sich bei seiner Forschung auf den letzten Lebensabschnitt, indem er Personen nach deren Wahrnehmung der eigenen Lebensenergie befragte. So wollte er herausfinden, ob sie in ihren letzten Lebensjahren eine Art von wiederkommender Energie verspürten, bevor es seines Erachtens endgültig schlechter wurde. Er war auch einer der ersten empirischen Forscher in der Psychologie, der sich intensiv mit dem Thema Tod im Alter auseinandersetzte. Eine genauere Unterteilung in ein jüngeres und ein älteres Alter wurden hier jedoch nicht vorgenommen.

Auch Cowdrey (1939) und Frank (1942) beschrieben in ihrer Forschung in erster Linie die medizinischen Aspekte des Alterns. Cowdrey ging in seinem Buch „Problem of Ageing“ neben psychologischen, klinischen und soziologischen Faktoren des Alters sogar auf die verschiedenen Organsystem sowie die Pflanzenkunde ein (Birren & Birren, 1990). Entwicklungsaspekte des sehr hohen Alters lassen sich bei Frank finden, der über die Veränderungen und Charakteristika schrieb, die mit dem Altern einhergehen. Auch Dewey (1939) beschäftigte sich mit Entwicklungsaspekten des Alters, indem er die seiner Meinung nach bestehenden zwei Seiten des Alters beschrieb – ein Konzept, das die Lebensspannenpsychologie später mit der Bezeichnung von Entwicklungsgewinnen und –verlusten aufgriff (z.B. Baltes, 1987). Auf der einen Seite wurden seiner Meinung nach Personen im hohen Alter immer reifer und weiser. Auf der anderen Seite, der biologischen Seite, mit zunehmendem Alter immer schwächer, verletzlicher und die Wahrscheinlichkeit, an einem Gebrechen zu sterben, immer grösser.

Vom wirklichen Beginn einer Psychologie der Hochaltrigkeit mit dem Gedanken der Entwicklungspsychologie über die Lebensspanne mit dem Fokus auf den letzten Lebensabschnitt kann erst in den 1940er Jahren gesprochen werden, als das erste Gerontologische Forschungszentrum der Nationalen Gesundheitsinstitute seine Türen öffnete. Fast zur gleichen Zeit entstanden auch die Gerontological Society of America (GSA) und die „Division on Maturity and Old Age“ der American Psychological Association (APA; Birren & Birren, 1990). Eine deutliche Abgrenzung zwischen dem jungen Alter und dem alten Alter gab es allerdings zu dieser Zeit noch nicht, auch wenn zu dieser Zeit hierfür die Grundlagen gelegt wurden.

3.1.4 Aktuelle Bedeutung der Hochaltrigkeitsforschung

Aktuell versteht sich die Psychologie der Hochaltrigkeit vor allem als empirische Wissenschaft. Der Fokus liegt dabei auf der Beschreibung und Erklärung der Veränderung von Strukturen und Prozessen im hohen Alter. Von wesentlicher Bedeutung sind dabei die soziale, emotionale und kognitive Entwicklung sowie die Wechselwirkungen mit gesellschaftlichen, sozialen und räumlichen Rahmenbedingungen. Von speziellem Interesse für ein Verständnis lebenslanger Entwicklung ist die Psychologie der Hochaltrigkeit und somit die Entwicklung am Ende der Lebenspanne aus zwei Hauptgründen.

Der erste Grund ist, dass Veränderungen im sehr hohen Alter sich nicht zwangsläufig nur auf eine Richtung der Entwicklung beziehen, nämlich auf die Zunahme, sondern es können darunter auch Abbauprozesse oder Verluste gemeint sein (Martin & Kliegel, 2008). Die Entwicklung über die Lebensspanne besitzt also einen multidirektionalen Charakter, geprägt durch Gewinne und Verluste über die gesamte Lebensspanne (vgl. Heckhausen, Dixon, & Baltes, 1989). Das Verhältnis von Gewinnen und Verlusten ändert sich im Verlauf des Lebens. Im Jugend- und frühen Erwachsenenalter überwiegen die Gewinne. Im späteren Erwachsenenalter und speziell bei Hochaltrigen kehrt sich dieses Verhältnis von Gewinnen und Verlusten um. Das heisst, mit zunehmendem Alter wird aus der positiven Differenz von Gewinnen und Verlusten eine negative (Baltes, 1987). Aus der bisherigen Forschung ist jedoch nicht ersichtlich, inwieweit sich diese Theorie auf die individuelle Ebene anwenden lässt. Obwohl beispielsweise gezeigt werden konnte, dass Personen im hohen Alter tendenziell eine Abnahme der kognitiven Fähigkeiten aufweisen, gibt es auch Individuen, bei denen dies nicht oder deutlich weniger der Fall ist. Diese zeigen eine konstante Leistung auch im Verlauf des hohen Alters oder sogar eine Steigerung der Leistung. Um das Verhältnis von Gewinnen und Verlusten im hohen Alter zu untersuchen, ist es deshalb wichtig, Unterschiede zwischen individuellen Verläufen anhand von Längsschnittstudien zu betrachten.

Obwohl, wie bereits erwähnt wurde, im hohen Alter im Durchschnitt die Verluste überwiegen, hat sich gezeigt, dass ein grosser Teil der hochaltrigen Personen die funktionale Autonomie erhalten kann. Gemäss Höpflinger und Hugentobler (2003) meistern 80% der 80-85-jährigen Personen ihr Leben unabhängig und bei den über 85-Jährigen sind es noch 65-70%. In diesem Zusammenhang ist von Interesse, wie es Personen schaffen, funktional autonom zu bleiben, obwohl sie meist weitaus weniger psychologische Ressourcen zur Verfügung haben als in ihren Jugend- und jungen Erwachsenenjahren. Trotz des Erhalts von unterschiedlichen Fähigkeiten scheinen es viele Hochaltrige zu schaffen, ihre Ressourcen optimal zu nutzen, um möglichst lange ihre funktionale Autonomie aufrecht zu erhalten. Eine grosse Herausforderung für die Hochaltrigkeitsforschung besteht darin heraus zu finden, welche Mechanismen dieser funktionalen Autonomie zugrunde liegen.

Dazu ist es hilfreich, Autonomie nicht als abhängige Variable zu betrachten, sondern sie in einem Wechselspiel von einzelnen Fähigkeiten, einzelnen Umwelten, der Plastizität der Fähigkeiten und der Beeinflussung der Umwelten zu sehen. In diesem Zusammenhang kann von der Ressourcen-Orchestrierung zur Stabilisierung von Lebensqualität und Autonomie gesprochen werden (Zöllig, Eschen, & Martin, 2009). Danach kann selbst bei geringer Ressourcenlage und geringer Ressourcenplastizität die Lebensqualität und die Autonomie auf drei Wegen aufrecht erhalten werden. Zum einen durch die geeignete Wahl von ressourcenadäquaten Umwelten, also beispielsweise Umwelten mit regelmässigen, gut vorhersehbaren Abläufen und geringerer Komplexität, zum anderen durch die Übung der vorhandenen Fähigkeiten und Ressourcen und schliesslich durch die Adaptation der Kriterien, die für die Bewertung der eigenen Lebensqualität und Autonomie herangezogen werden(vgl. Zöllig et al., 2009). Das sehr hohe Alter mit einer durchschnittlich geringeren Ressourcenlage macht Adaptationsprozesse auf allen drei Wegen eher erforderlich als in anderen Gruppen und die Adaptation ist für die psychische Gesundheit und das Überleben der Hochaltrigen entscheidender als für jüngere Altersgruppen. Hochaltrige bieten sich daher für die Untersuchung der Grenzen der Adaptivität menschlicher Entwicklung geradezu an.

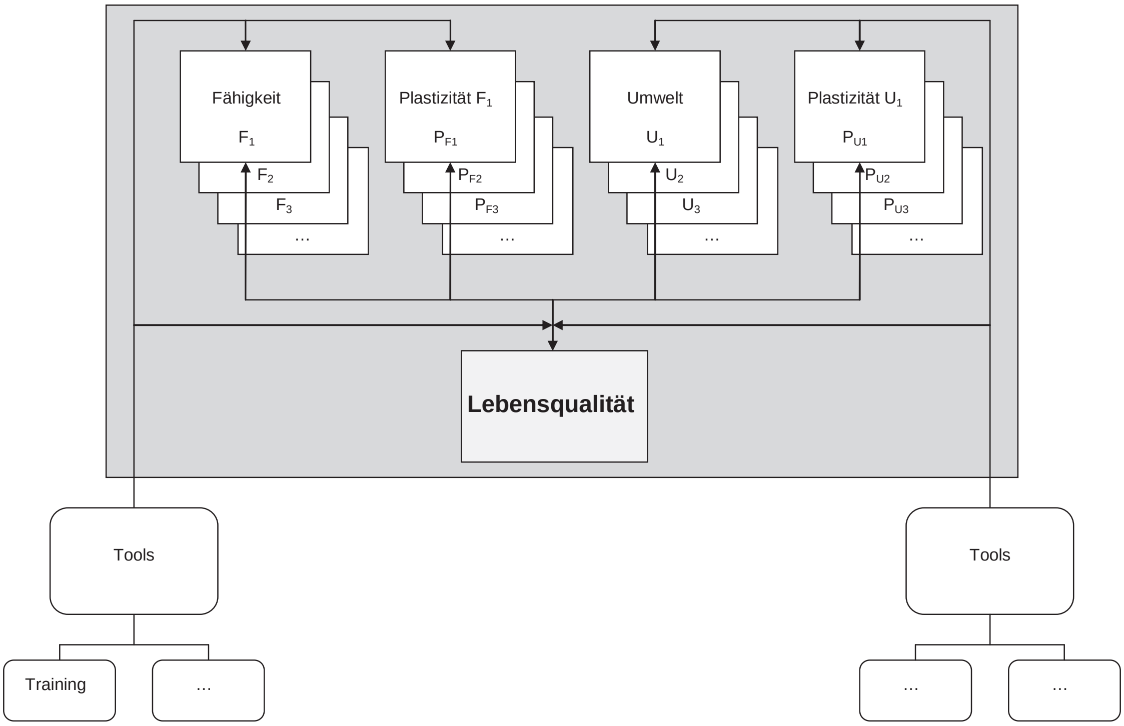

Abbildung 1. Orchestrierungsmodell des Lebensqualitätsmanagements im hohen Alter (nach Zöllig et al., 2009).

Der zweite Hauptgrund der Bedeutung der Psychologie der Hochaltrigkeit ist die vorhersehbare Tatsache, dass die Erforschung der heute 85- bis über 100-jährigen einen Blick in die Zukunft des „jungen Alters“ erlaubt: Betrachtet man die demographische Entwicklung der heutigen Weltbevölkerung, so wird sich laut Berechnungen des Statistischen Bundesamtes Deutschland die Lebenserwartung der 65-Jährigen bis ins Jahr 2050 im Durchschnitt um 4.5 Jahre erhöhen. Zudem steigt die Zahl der über 80-Jährigen von heute ca. 4 Millionen bis ins Jahr 2050 auf ca. 10 Millionen (Eisenmenger, Pötzsch, & Sommer, 2006). Gemäss Oeppen und Vaupel (2002) hat sich die Lebenserwartung seit 1840 pro Jahr um drei Monate erhöht. Extrapoliert man diese Trends in die Zukunft, bedeutet dies, dass in Deutschland im Jahr 2007 geborene Kinder eine Lebenserwartung von 102 Jahren besitzen werden. Die zukünftige Steigerung der Lebenserwartung ist in erster Linie auf die sinkende Mortalität im hohen Alter zurückzuführen (K. Christensen, Doblhammer, Rau, & Vaupel, 2009). Es ist also vorhersehbar, dass die heute geborenen Kinder das Dritte Alter von 65 bis über 100 Jahre erreichen werden und wir mit der Erforschung des heutigen hohen Alters bereits jetzt wichtige Einsichten über mögliche Anpassungsprozesse der zukünftig „jungen alten“ Menschen erhalten können.

3.1.5 Kognitive Hochaltrigkeitsforschung

Unter den für eine selbstständige Lebensgestaltung und Alltagsbewältigung im höchsten Alter wichtigsten Ressourcen nehmen die kognitiven Ressourcen und die Intelligenz eine herausragende Stellung ein. So konnte die Arbeitsgruppe um Lawton zeigen, dass vor allem der Verlust der kognitiven Gesundheit für Hochaltrige einen grossen Leidensdruck mit sich bringt. So äussern 72% der Personen im Alter von 70 Jahren und älter, sie würden lieber sterben, als geistig verwirrt in einem Heim zu leben. Dies zeigt, dass Personen tendenziell die geistige Gesundheit für ihr Wohlbefinden sehr hoch gewichten (Lawton et al., 1999). Da die kognitive Entwicklung und Veränderung im hohen Alter nicht nur für die Wissenschaft sondern auch für das Individuum von grossem Interesse ist und dieses Gebiet extremes Forschungspotential bietet, möchten wir uns im Folgenden in erster Linie auf die kognitive Entwicklung am Ende der Lebensspanne beziehen.

Die Kognition ist noch aus einem anderen Grund von erheblicher Bedeutung: Wie Auswertungen der Lebenserwartungsdaten von extrem hoch gebildeten Personen belegen, geht eine lange formale Ausbildung und kognitive Aktivität einerseits mit auch im Alter höherer kognitiver Leistungsfähigkeit andererseits einher (Hultsch et al., 1999; Willis & Schaie, 2005). Sie könnte sogar mit einer höheren Lebenserwartung assoziiert sein. Eine eigene, 2007 durchgeführte Untersuchung der Lebenserwartungsdaten aller seit ihrer Gründung 1833 an der Universität Zürich angestellten Professoren, die zwischen 1763 und 1909 geboren wurden (N = 489; aufgrund der geringen Zahl von bisher verstorbenen Professorinnen konnten nur die Daten der männlichen Professoren ausgewertet werden), ergab im Vergleich zur männlichen Zürcher Vergleichsbevölkerung von Personen, die mindestens 31 Jahre alt wurden (dem Lebensalter des jüngsten verstorbenen Professors) eine um 4.4 Jahre höhere Lebenserwartung. Deutlich wird bei den Daten darüber hinaus, dass der signifikante Vorteil von extrem hoher Bildung auch nach Überschreiten der mittleren Lebenserwartung anhält, also auch im höheren Alter bis etwa 95 Jahre (s. Abbildung 2).

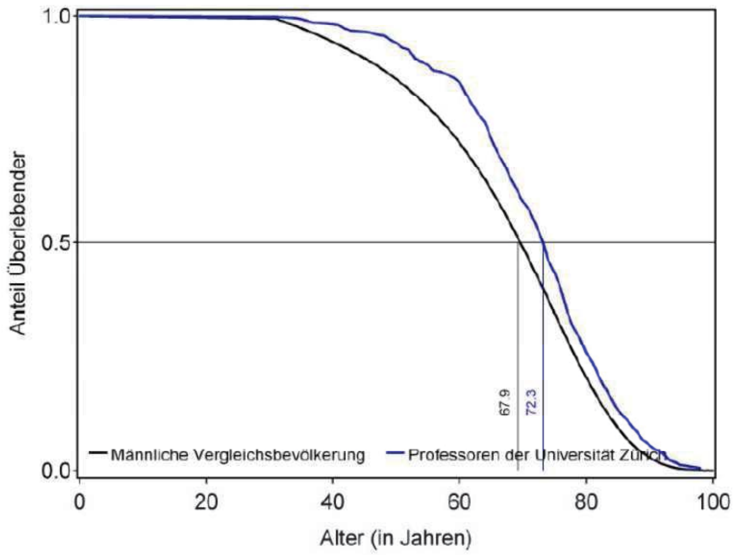

Abbildung 2: Vergleich der Lebenserwartung von Professoren und Vergleichsbevölkerung für die Geburtsjahrgänge 1763-1909 zum Stichtag 31.12.2006 (nach Martin, Zimprich, & Schumacher, 2007).

In diesem Zusammenhang ist von Bedeutung, dass durch die neuroanatomische Forschung erhebliche Plastizitätspotenziale aufgezeigt werden können. So konnte gezeigt werden, dass bei alternden Gehirnen nicht nur Abbauprozesse existieren, sondern anhand von gezielten Trainings gewisse Hirnregionen einen plastischen Charakter besitzen. Mittlerweile bedient sich nicht mehr nur die Neuroanatomie des Begriffs der Plastizität sondern auch die Neuropsychologie und Gerontopsychologie, die herauszufinden versuchen, inwieweit sich diese Befunde auf die Gehirne von Hochaltrigen übertragen lassen. Dazu sind Daten zur normalen Entwicklung kognitiver Leistungen im sehr hohen Alter von ausschlaggebender

Bedeutung. Bis jetzt war man der Meinung, dass mit Ausnahme von wenigen Fähigkeiten - wie beispielsweise der kristallinen Intelligenz - die Mehrheit der kognitiven Fähigkeiten im Alter abnehmen. Bis anhin wurde dies jedoch selten bei Hochaltrigen untersucht und wenn, dann meist mit Querschnitt- und nicht mit Längsschnittstudien. Problematisch bei der Querschnittforschung ist, dass man individuelle Veränderungs- und Entwicklungsprozesse zugunsten der Betrachtung von Altersunterschieden vernachlässigt.

Es ist aus methodischen Gründen zunächst verständlich, warum Längsschnittstudien mit sehr alten Personen besondere Herausforderungen darstellen. So ist beispielsweise eine gleich grosse Stichprobe Hundertjähriger aus einer wesentlich kleineren Grundgesamtheit gezogen als eine Repräsentativstichprobe von 80-jährigen (Martin & Kliegel, 2008). Von den untersuchten Hundertjährigen überlebt heute nur ein kleiner Teil lange genug, um an einer möglicherweise erst Jahre später stattfindenden Wiederholungsmessung teilnehmen zu können. Dennoch führt unseres Erachtens kein Weg an geeigneten längsschnittlichen Designs vorbei. Dazu eine Illustration aus einem anderen Bereich: Vergleicht man im Querschnitt 60- mit 100-jährigen, so ist bei den 60-jährigen ein hoher Blutdruck ein eindeutiger Risikofaktor für Herzinfarkte, aber praktisch alle Hundertjährigen weisen einen erhöhten Blutdruck auf. Man kann nun entweder vermuten, dass die Personen, die mit einem erhöhten Blutdruck von einem Herzinfarkt verschont bleiben anschliessend sehr alt werden oder aber, dass die Personen sehr alt werden, deren Blutdruck sich in Anpassung an ein zunehmend weniger flexibles Gefässsystem erhöht hat. Übertragen auf psychologische Sachverhalte wie die kognitiven Ressourcen ist ebenso fraglich, inwiefern auch sehr alte Personen in der Lage sind, ihre Leistungen den veränderten Erfordernissen ihrer Lebenssituation anzupassen – und dies ist nur in Längsschnittstudien möglich. Man könnte sogar sagen, dass gerade bei Hochaltrigen die Längsschnittforschung von Interesse ist, da man so erkennen kann, ob es im sehr hohen Alter Personen gibt, bei denen die kognitive Leistung über die Zeit konstant bleibt oder sogar Verbesserungen möglich sind. Diese Daten würden wichtige Hinweise auf die möglicherweise nicht vorhandenen Grenzen der kognitiven Plastizität liefern. Speziell in Hinsicht auf die steigende Zahl von kognitiv beeinträchtigen Personen im hohen Alter ist es darüber hinaus von Bedeutung, individuelle Entwicklungsverläufe zu betrachten und daraus mögliche Schutzfaktoren zum Erhalt oder zur positiven Beeinflussung kognitiver Kompetenzen herauszukristallisieren. Das Ziel dieses Kapitels ist es deshalb als nächstes, einen Überblick über Längsschnittstudien zur kognitiven Entwicklung bei Hochaltrigen zu geben, die verschiedenen methodischen Herausforderungen der psychologischen Höchstaltrigenforschung aufzuzeigen und weitere Forschungsmöglichkeiten im Gebiet der kognitiven Hochaltrigkeitspsychologie zu präsentieren.

3.1.5.1 Kognitive Längsschnittstudien.

Tabelle 1 gibt einen Überblick über die wichtigsten Längsschnittstudien, die kognitive Fähigkeiten bei Hochaltrigen untersucht haben. Bei der Analyse der Studien wurden in erster Linie die kognitiven Studien mit über 80-Jährigen von Hofer und Piccinin (2007) übernommen und überarbeitet und durch weitere Studien der Webseite der „Integrative Analysis of Longitudinal Studies on Aging (IALSA)“ und des „Nationale Institute on Aging (NIA)“ ergänzt. Dabei wurden ausschliesslich Studien einbezogen, deren Laufzeit bis zum Jahre 2009 mindestens fünf Jahre betrug und bei denen zwei oder mehr Messzeitpunkte von über 80-Jährigen erhoben wurden.

Bei genauerer Betrachtung der Tabelle 1 fällt auf, dass, obwohl alle Studien Versuchsteilnehmer im Alter von über 80 beinhalten, sich wenige darunter befinden, die sich ausschliesslich auf Personen oberhalb der mittleren Lebenserwartung konzentrieren. Lediglich sieben der 66 Studien fokussieren vom ersten Messzeitpunkt an auf Personen, die 80 Jahre oder älter sind (Fredericton, H85, HD 100, Lund, NECS, OCTO-Twin und SWILSO-O). Auf ähnliche Befunde sind auch Smith und Zank (2002) gestossen. Sie haben 32 psychologische Studien auf den Anteil von 85-jährigen Personen untersucht. Unter den von ihnen betrachteten

Studien befanden sich fünf, welche einen 100%-Anteil von über 85-Jährigen besassen. Ihre Resultate weisen darauf hin, dass sich viele grosse und bekannte internationale Altersstudien vordergründig auf Stichproben im jungen und mittleren Erwachsenenalter beziehen.

Längsschnittstudien zur kognitiven Entwicklung im hohen Alter (80+ Jahre)

Studienname	Laufzeit	N (T1)[a]	Alter (T1)[b]	T2-T1[c]	Akronym
Aging in Manitoba	1971-	8950	60+	5	AIM
Asset and Health Dynamics Among the Oldest Old	1993-	7447	70-89	2	AHEAD
Australian Longitudinal Study of Aging	1992-	2087	70+	1	ALSA
Baltimore Longitudinal Study of Aging	1958-	260	20-96	2	BLSA
Berkeley Older Generation Study	1968-1982	94	59-79	14	--
Berlin Aging Study	1990-	516	70-103	2	BASE
Betula Project	1988-1998	3500	35-80	5	Betula
Bonn Longitudinal Study	1965-1981	222	60-75	1	BOLSA
Cambridge City Over 75 Cohort Study	1985-	2616	75+	1	CC75C
Canadian Multicentre Osteoporosis Study	1996-2008	9423	25+	n. b.	CaMos
Canadian Study of Health and Aging	1991-2001	10263	65+	5	CSHA
Canberra Longitudinal Study	1990-2002	897	70-93	4	CLS
Cardiovascular Health Study	1989-1999	5888	65-100	1	CSH
Chicago Health and Aging Project	1993-	10121	65+	3	CHAP
Cross-European Longitudinal Study of Ageing	2002-	1500	30-85	n. b.	EXCELSA
Duke Longitudinal Study of Normal Aging	1956-1976	267	60-94	3.5	DLSNA
Einstein Aging Studies	1980-	488	70-90	1	EAS
Epidemiology of Dementia in Cache Co., Utah	1995-	5092	65+	3	--
English Longitudinal Study	2002-	12100	50-100	1	ELSA

Studienname	Laufzeit	N (T1)[a]	Alter (T1)[b]	T2-T1[c]	Akronym
Established Populations for Epidemiologic Studies of the Elderly	1981-1993	14456	65+	2	EPESE
Fredericton 80+ Study	1998-2008	387	80	n. b.	Fredericton
Gender Study of Unlike Sex Dizygotic Twins	1995-	500	69-81	4	GENDER
Georgia Centenarian Study	1988-	300	60+	4	GCS
Gerontological and Geriatric Population Studies in Gothenburg	1971-	1000	70	5	H70
Groningen Longitudinal Aging Study	1992-	5297	57-99	1	GLAS
Göteborg Study	1985-	494	85+	3	H85
Health, Aging and Body Composition Study	1997-2004	3075	70-79	1	Health ABC
Healthy Older People in Edinburgh Study	1990-	597	70-88	n. b.	HOPE
Heidelberg Centenarian Project	2001-	91	100+	1.5	HD 100
Honolulu-Asia Aging Study	1991-	3734	71-93	3	HAAS
Italian Longitudinal Study on Aging	1992-2004	5493	65-84	3	ILSA
Kungsholmen Project	1987-1999	327	75+	4	--
Longbeach Longitudinal Study	1978-	509	55-87	3	LBLS
Longitudinal Aging Study Amsterdam	1992-	3107	55-85	3	LASA
Longitudinal Study of Aging in Africa	2004-	3500	50+	n. b.	LSAA
Longitudinal Study of Aging I	1984-1990	7527	70+	2	LSOA
Longitudinal Study of Aging II	1994-2000	9447	70+	3	LSOA II
Longitudinal Studies of Cognitive Change in Normal, Healthy Old Age	1982-	6187	49-96	n. b.	LSDD
Lund 80+ Study	1988-	211	80+	5	LUND
Maastricht Aging Study	1992-	2000	24-81	3-5	MAAS

Studienname	Laufzeit	N (T1)[a]	Alter (T1)[b]	T2-T1[c]	Akronym
McArthur Studies of Successful Aging	1988-1996	1192	70-79	3	McArthur
Melton Mowbray Ageing Project	1981-	3000	75+	4	MMAP
Medical Research Council Cognitive Function and Ageing Study	1991-	13000	65+	n. b.	CFAS
Monongahela Valley Independent Elders Survey	1987-2002	2002	65+	2	MoVIES
National Health and Nutrition Examination Survey Follow-Up	1971-1992	14407	25-74	11	NHEFS
National Long Term Care Survey	1982-	19000	65+	2	NLTCS
National Population Health Survey	1994-	17276	0+	2	NPHS
New England Centenarian Study	1994-	46	100+	n. b.	NECS
New Mexico Aging Process Study	1979-2003	299	65+	1	NMAPS
Normative Aging Study	1963-	2280	21-81	3-5	NAS
Nordic Research on Aging	1989-	400	75	5	NORA
Nottingham Longitudinal Study of Activity and Aging	1985-1993	1042	65+	4	NLSAA
Nun Study	1986-	678	75-106	1	NUN
Octogenarian Twin Study	1990-	702	80+	2	OCTO-Twin
Personnes âgées QUID	1988-2003	4134	65+	n. b.	PAQUID
Rancho Bernardo Study	1972-	1000-6000	20+	n. b.	Bernardo
Rotterdam Study	1990-	7983	55-106	4	Rotterdam
Seattle Longitudinal Study	1956-	5000	22-70	7	SLS
Southampton Aging Project	1977-1998	340	65+	11	SAP
Survey on Health, Aging and Retirement in Europe	2004-	31115	50+	2	SHARE
Study of Osteoporotic Fractures	1986-	9704	65+	4	SOF

Studienname	Laufzeit	N (T1)[a]	Alter (T1)[b]	T2-T1[c]	Akronym
Swedish Adoption/Twin Study of Aging	1984-	1500	40-84	3	SATSA
Swiss Interdisciplinary Longitudinal Study on the Oldest-Old	1994-	714	80-85	1	SWILSO-O
Victoria Longitudinal Study	1986-	484	55-85	3	VLS
Women's Health Initiative Memory Study	1996-2005	7480	65-79	n. b.	WHAS

[a] Anzahl der Versuchspersonen der Kernstichprobe zum ersten Messzeitpunkt

[b] Altersrange der Kernstichprobe zum ersten Messzeitpunkt

[c] Zeitintervall zwischen dem ersten und zweiten Messzeitpunkt

Im Folgenden wird anhand von drei Studien der momentane Stand der Längsschnittforschung im hohen Alter erläutert. Es werden Studien beschrieben, die sich bezüglich ihrer Schichtung, Repräsentativität und ihres Altersranges unterscheiden und demzufolge einen breiten Überblick über die Längsschnittforschung im hohen Alter vermitteln.

In der *Berliner Altersstudie* (BASE) wurde darauf geachtet, dass die Teilnehmenden der Kernstichprobe nach Alter und Geschlecht stratifiziert wurden. Das heisst, dass sich in jeder der sechs Altersgruppen genau gleich viele Männer wie Frauen befanden. Diese Schichtung nach Alter und Geschlecht erlaubt den Vergleich von Teilgruppen mit ausreichender statistischer Aussagekraft, insbesondere ältere Männer sind dadurch im Vergleich zur Gesamtbevölkerung deutlich überrepräsentiert.

Die Berliner Altersstudie startete im Jahre 1990 mit einer Kernstichprobe von 516 Personen im Alter von 70 bis 103 Jahren, die bezüglich ihrer geistigen und körperlichen Gesundheit, ihrer intellektuellen Leistungsfähigkeit und psychischen Befindlichkeit sowie ihrer sozialen und ökonomischen Situation getestet wurden. Nach dieser Kernuntersuchung wurden die Überlebenden längsschnittlich sieben weitere Male getestet. Bei der Längsschnittuntersuchung bestand die kognitive Testbatterie aus acht Tests, wobei jeweils zwei Tests eine der folgenden kognitiven Fähigkeiten prüfen sollten: Verarbeitungsgeschwindigkeit (gemessen durch Zahlen-Buchstaben und identische Bilder), episodisches Gedächtnis (gemessen durch Paarassoziationen und Gedächtnisaufgaben für Texte), Flüssigkeit (gemessen durch Kategorien und Wortanfang) und Wissen (gemessen durch Wortschatz und Wortsichtung). Zusätzlich wurde aus den vier kognitiven Fähigkeiten ein Intelligenzmass berechnet. Die Befunde von Singer, Verhaeghen, Ghisletta, Lindenberger und Baltes (2003), auf die im Folgenden Bezug genommen wird, beziehen sich auf drei Testzeitpunkte, die im Abstand von ca. vier beziehungsweise sechs Jahren nach der ersten

Erhebung durchgeführt wurden. Singer et al. (2003) haben die Querschnittdaten aller Versuchspersonen (N = 516, Querschnittgruppe), die an der ursprünglichen Erhebung teilgenommen haben, mit den Querschnitt- und Längsschnittdaten der nach sechs Jahren verbliebenen Versuchspersonen (N = 132, Längsschnittgruppe) verglichen. Es stellte sich dabei heraus, dass sich der Altersverlauf in den kognitiven Fähigkeiten bei den Quer- und Längsschnittdaten der Längsschnittgruppe im Gegensatz zur Querschnittgruppe nicht unterscheiden. Der Altersverlauf der Querschnittgruppe hatte im Vergleich zur Längsschnittgruppe einen steileren Verlauf, d.h. die Leistungen nahmen über das Alter stärker ab. Betrachtet man die Leistung in den verschiedenen kognitiven Fähigkeiten, so wird ersichtlich, dass Verarbeitungsgeschwindigkeit, Gedächtnis und Flüssigkeit ähnliche mit dem Alter einhergehende Verluste aufweisen - im Unterschied zum Wissen, welches bis zum Alter von 90 Jahren nahezu konstant blieb. Die verschiedenen kognitiven Fähigkeiten zeigen im Längsschnitt, dass mehr Veränderungen in der Gruppe der sehr Alten (78-100 Jahre) vorkommen als in der Gruppe der Alten (70-77 Jahre).

Bei der *Seattle Längsschnittstudie* (SLS) wurde weniger auf die Verteilungen des Alters und des Geschlechts innerhalb der Gruppen geachtet als vielmehr auf die Repräsentativität der Stichprobe. In regelmässigen Abständen von sieben Jahren wurde die Kernstichprobe durch eine weitere Gruppe von zufällig ausgewählten Mitgliedern einer Krankenversicherung ergänzt (Martin & Kliegel, 2010).

Die Seattle Longitudinal Study hat ihren Ursprung im Jahre 1956. Warner Schaie testete im Rahmen seiner Doktorarbeit 500 Personen bezüglich ihrer kognitiven Fähigkeiten. 1963 wurde die erste Follow-up-Untersuchung durchgeführt, welche die ursprünglich geplante Querschnittstudie zu einer Längsschnittstudie erweiterte. Die darauffolgenden Testungen fanden im Abstand von 7 Jahren statt, wobei zu den Längsschnittdaten auch immer wieder Querschnittdaten von neuen Kohorten erfasst wurden. Bei den Teilnehmenden wurden u.a. die kognitiven Fähigkeiten induktives Denken, räumliche Wahrnehmung, verbales Verständnis, Wortflüssigkeit und Zahlenflüssigkeit untersucht. Betrachtet man den Verlauf der verschiedenen kognitiven Fähigkeiten über einen Zeitraum von 35 Jahren bei Personen im Alter von 25 bis 88 Jahren, so fällt auf, dass eine Abnahme der kognitiven Leistung erst einige Jahre nach dem Erreichen des mittleren Erwachsenenalters eintrifft. Eine signifikante Verschlechterung der Leistung in der Wort- und Zahlenflüssigkeit beginnt ab dem Alter von 67 Jahren und bei den anderen aufgeführten kognitiven Fähigkeiten sogar erst ab dem Alter von 74 Jahren. Diese Befunde unterscheiden sich von den Resultaten der Querschnittdaten insofern, dass bei diesen ein Abfall von verschiedenen kognitiven Fähigkeiten wie beispielsweise des induktiven Denkens und der räumlichen Wahrnehmung bereits im Alter von 25 Jahren beobachtet werden können (Schaie, 2005).

Die *Georgia Centenarian Study* (GCS) fokussierte sich bei der Auswahl ihrer Versuchspersonen speziell auf die Altersgruppe der extremen Hochaltrigen. Sie untersuchte in erster Linie kognitiv gesunde Personen, die das 100. Lebensjahr erreicht hatten. Bei der Georgia Centenarian Study hat demgemäss eine bewusste Selektion bezüglich Alter und kognitiver Gesundheit stattgefunden.

Der erste Messzeitpunkt der Georgia Centenarian Study fand im Jahre 1988 statt. Neben der Gruppe von ca. 100 Hundertjährigen wurde auch eine Gruppe von 60- und 80-Jährigen untersucht. Das Ziel der ersten Phase des Projektes war es, die speziellen Adaptationsmechanismen von kognitiv intakten Personen zu untersuchen - interessanterweise aufgrund von Querschnittdaten. Sechs Jahre später folgte eine Folgeerhebung, bei der dieselben Fragestellungen im Längsschnitt betrachtet wurden. Die kognitiven Messinstrumente, die bei der Georgia Centenarian Study eingesetzt wurden, setzten sich zusammen aus vier Untertests der WAIS Testbatterie (Vokabular, Blockdesign, Arithmetik und Bilderanordnung) sowie einem Test zum Paarassoziationslernen, dem Wiedergeben von

Präsidenten und dem Wiedererkennen von gelerntem Material (Poon et al., 1992). Bei der Analyse der Daten wurden einerseits die Leistungen der verschiedenen Altersgruppen miteinander verglichen und andererseits die interindividuellen Variationen in der kognitiven Leistung der verschiedenen Altersgruppen betrachtet. Wie zu erwarten war, zeigten die jüngeren Altersgruppen im Durchschnitt eine bessere Leistung in den kognitiven Tests als ihre Vergleichsgruppe von Hundertjährigen. Bei den interindividuellen Variationen zeigte sich, dass bei Fähigkeiten, die auf Erfahrung basieren (Vokabular, Wiedergeben von Präsidenten und Wiedererkennen von gelerntem Material) und einen ziemlich stabilen Charakter über die Lebensspanne aufweisen, mit zunehmendem Alter auch eine Zunahme der Variabilität auftritt. Im Gegensatz hierzu wurde bei prozessbasierten Fähigkeiten (Blockdesign, Arithmetik und Paarassoziationslernen) genau der gegenteilige Effekt beobachtet. Bei kognitiven Aufgaben, bei denen Personen mit zunehmendem Alter tendenziell schlechtere Leistungen erbringen, nahm die interindividuelle Variabilität der Leistung ab (Poon et al., 1992). Dies ist jedoch möglicherweise ein Artefakt der typischerweise zu findenden hohen Korrelation zwischen Mittelwerten und Variabilitätsmassen.

Insgesamt haben die drei beispielhaft ausgewählten Studien wichtige Beiträge zur Psychologie der Hochaltrigkeit geliefert, insbesondere durch die Kombination von Quer- und Längsschnittstudien. So deuten besonders die längsschnittlich meist günstigeren Entwicklungsverläufe kognitiver Fähigkeiten darauf hin, dass auch im höchsten Alter (a) nachkommende Kohorten signifikant günstigere Entwicklungsverläufe aufweisen und (b) individuelle Unterschiede im Lebensstil zu günstigeren Entwicklungsverläufen beitragen. Bisher ist jedoch unklar, inwiefern Veränderungen von Aktivitäten und Lebensstil im höchsten Alter Auswirkungen auf individuelle Entwicklungsverläufe haben, es also tatsächlich zu Adaptationen von Verhalten und Leistungen kommt. Wichtig sind auch die

Befunde zur unterschiedlichen Veränderungssensitivität innerhalb der Gruppe sehr alter Personen. Diese unterstreichen, dass es in den jüngeren Altersgruppen möglicherweise mit weniger Aufwand gelingt, eine stabile „Orchestrierung“ der Leistungsfähigkeit herzustellen, in den älteren Altersgruppen die Möglichkeiten zur Orchestrierung etwa durch markant verringerte Einzelressourcen jedoch geringer ist. Dies stünde im Einklang mit einer Dedifferenzierung von Fähigkeiten erst innerhalb des höchsten Alters, die sowohl für Persönlichkeitseigenschaften (Allemand, Zimprich, & Martin, 2008) wie für kognitive Fähigkeiten nachgewiesen werden kann (Zimprich & Martin, 2009). Darüber hinaus verweisen diese Befunde auf die Bedeutung der Erforschung von Adaptationsprozessen im extrem hohen Alter, da unter den Grenzbedingungen kognitiver Fähigkeiten wie im extrem hohen Alter die effiziente Ressourcenorchestrierung umso wichtiger für die Aufrechterhaltung alltagswichtiger Kompetenzen wird und die Mechanismen, die zur Effizienzsteigerung führen, umso besser isoliert werden können (Schönemann-Gieck et al., 2003; Schumacher & Martin, 2009a).

3.1.5.2 Methodische Herausforderungen der Hochaltrigkeitsforschung.

Die aus unserer Sicht wichtigste Fragestellung der kognitiven Hochaltrigkeitsforschung ist die nach der Fähigkeit, bis ins extrem hohe Alter die Orchestrierung von kognitiven Ressourcen zugunsten der Aufrechterhaltung von Autonomie, Wohlbefinden, sozialer Integration und Lebensqualität zu adaptieren. Mit anderen Worten geht es darum, ob extrem alte Personen aufgrund stabiler und nicht veränderbarer Eigenschaften und Leistungsverlusten überlebt haben – die Überlebens-Hypothese – oder ob prinzipiell bis ins höchste Alter eine Adaptation der Ressourcenorchestrierung – die Adaptations-Hypothese – möglich ist. Diese Frage kann nur mit Hilfe von Längsschnittdaten beantwortet werden. Allerdings ist die längsschnittliche Erforschung des sehr hohen Alters mit fünf bisher ungelösten Herausforderungen konfrontiert, die die bestehenden Studien jeweils unterschiedlich zu umgehen versuchen.

Eine Herausforderung liegt in der zunehmenden Selektivität von Stichproben mit zunehmendem Alter (Ghisletta, McArdle, & Lindenberger, 2006). So waren die jüngsten Männer der BASE weniger als 1% der Berliner Gesamtpopulation der gleichen Altersgruppe, die ältesten dagegen mehr als 10% (vgl. Martin & Kliegel, 2008). Würde man noch ältere Personen untersuchen, etwa die so genannten „Super-Centenarians" der über 110-Jährigen (Maier, Gampe, Jeune, Robine, & Vaupel, 2010), dann würde die Ausschöpfungsquote bis zu 100% nach oben gehen. Damit gibt es nicht nur Unterschiede in der Selektivität zwischen den untersuchten Männern und Frauen, darüber hinaus ist auch nicht von vornherein klar, ob Zusammenhänge von Variablen innerhalb der verschiedenen Altersgruppen die gleichen sind. Durch die Selektion in solchen geschichteten Stichproben oder die unterschiedliche Varianz von Variablen in Repräsentativstichproben mit unterschiedlich vielen jungen und alten Personen, können die Beiträge einzelner Indikatoren (wie z.B. Wortflüssigkeit oder Weltwissen) zu latenten Konstrukten (wie z.B. fluide oder kristalline Intelligenz) unterschiedlich sein und unterschiedliche inhaltliche Bedeutungen haben. Mit dem Problem der Selektivität einher geht auch die Herausforderung, dass Stichproben von über 95-jährigen selbst über einen Folgezeitraum von 12 Monaten durch ein erhebliches Mass an Mortalität gekennzeichnet sind (Ghisletta & Spini, 2004). Werden in die längsschnittlichen Auswertungen nur die Personen mit vollständigen Datensätzen aufgenommen, so bleiben wertvolle Informationen von Personen ungenutzt, die nicht an allen Messzeitpunkten teilgenommen haben. Die Verwendung aller Daten ist mit Hilfe moderner statistischer Modelle möglich, dabei müssen jedoch eine Reihe von wichtigen Anforderungen an die Datenqualität erfüllt sein (vgl. Ghisletta, 2008; Zimprich, 2008; Zimprich & Martin, 2009).

Eine zweite Herausforderung liegt darin, dass gerade bei kognitiven Längsschnittstudien eine Tendenz besteht, dass leistungsfähigere Personen bei der ersten Testung besser abschneiden als weniger leistungsfähige Personen und deshalb auch eine höhere Motivation besitzen, an einer Folgeerhebung teilzunehmen. Zudem scheiden durch Mortalität im Normalfall Personen aus, deren kognitive und physische Gesundheit im Vergleich zu der Gesamtstichprobe unter dem Durchschnitt liegt. Beides zusammen hat zur Folge, dass bei Längsschnittstudien eine Verzerrung ins Positive vorliegt, das heisst, altersbedingte Abnahmeprozesse weniger stark ausfallen, als dies normalerweise der Fall wäre. Dies ist insbesondere bei Längsschnittstudien mit sehr alten Personen wirksam, weil hier Verringerungen der Leistungsfähigkeit die selbstständige Lebensführung gefährden oder beeinträchtigen können. Umgekehrt kann es gerade bei den Stichproben sehr alter Personen vorkommen, dass bereits in der Ausgangsstichprobe subsyndromale Erscheinungsformen psychischer, insbesondere demenzieller Erkrankungen vorliegen. Dadurch bewegt sich die Leistungsfähigkeit betroffener Personen zu einem früheren Zeitpunkt bezogen auf den Altersdurchschnitt zwar noch im normalen Streuungsbereich, sie ist jedoch zumindest teilweise erkrankungsbedingt verringert. Dies führt zu einer Unterschätzung der tatsächlichen Leistungsentwicklung der normalen, nicht von Erkrankungen betroffenen Untersuchungspopulation. Beide, Über- wie Unterschätzungen können also die Interpretation der Längsschnittdaten bei extrem Hochaltrigen stärker beeinflussen, als das bei jüngeren Altersgruppen der Fall ist.

Es können sich weitere methodische Herausforderungen bei der psychologischen Hochaltrigkeitsforschung ergeben, die weder quer- noch längsschnittspezifisch sind. Da ältere Personen mit kognitiver Beeinträchtigung nicht immer in der Lage sind, selbst ein reliables Urteil über ihre Fähigkeiten abzugeben, gibt es die Möglichkeit der Fremdbeurteilung durch einen Proxy. Diese Proxybeurteilung kann durch ein

Familienmitglied, einen engen Bekannten oder eine Pflegepersonen durchgeführt werden. Es hat sich jedoch gezeigt, dass die Fremdbeurteilungen nicht immer mit den Selbstbeurteilungen übereinstimmen – und dennoch als korrekt gelten können. Dabei muss berücksichtigt werden, dass die Quellen, auf denen das Urteil beruht, sich zwischen den Auskunftgebenden unterscheidet. So ist für aussenstehende ExpertInnen für die Beurteilung der Gesundheit von Hundertjährigen die funktionale Gesundheit von vorrangiger Bedeutung, für Hundertjährige selbst eher die emotionale und kognitive Unversehrtheit (Schönemann-Gieck et al., 2003).

Eine dritte Herausforderung liegt in der Wahl der Messabstände und der Entscheidung über ein prospektives Forschungsdesign. Einerseits sind im Hinblick auf Adaptationsprozesse im höchsten Alter mehrjährige Beobachtungszeiträume erforderlich, andererseits muss aufgrund der hohen Mortalität bei prospektiven Studien mit erheblichen Stichprobenausfällen und den entsprechenden Ergebnisverzerrungen gerechnet werden. Die Erhöhung der Ausgangsstichprobengrössen auf das erforderliche Mass ist wiederum ökonomisch meist nicht zu leisten. Denkbar ist in diesem Zusammenhang zum einen, sich auf kürzerfristige Adaptationsprozesse zu konzentrieren, insbesondere wie sie im Zusammenhang mit Interventions- oder Rehabilitationsstudien möglich sind. In diesem Fall werden quasi während eines Messzeitpunkts wiederholt Daten erhoben und man erhält einen „Längsschnitt im Längsschnitt“. Zum anderen kann allenfalls – und dafür haben wir im vorliegenden Kapitel die aktiven Längsschnittstudien zum Thema zusammengestellt – auf bereits zu früheren Zeiten erfasste Daten derselben Personen zurückgegriffen werden. Dies macht sich beispielsweise seit einigen Jahren die SLS zunutze, indem sie Personen, die nach sieben Jahren einen markanten Leistungsverlust in einer intellektuellen Fähigkeit aufweisen, ab diesem Zeitpunkt in kürzeren Einjahresabständen mit Instrumenten weiter verfolgt, die zur vergleichbar differenzierten Erfassung der kognitiven Entwicklung einen grösseren

Erfassungsbereich nach unten aufweisen. Den unter Umständen schnelleren Entwicklungsveränderungen im höchsten Alter kann man erhebungstechnisch so gerecht werden, indem die Messabstände ab einer markanten Verringerung kognitiver Leistungen nicht mehr aufgrund des chronologischen Alters, sondern anhand der Veränderung der Leistung selbst oder dem fortschreitenden Schweregrad einer Erkrankung festgelegt werden. Eine vierte Herausforderung liegt mehr auf der konzeptionellen Ebene. Da bei extrem Hochaltrigen Personen der zeitliche Abstand zur Geburt, also das chronologische Alter, möglicherweise weniger zur Erklärung von Altersveränderungen beiträgt, ist vorgeschlagen worden, Veränderungen eher im Hinblick auf die Nähe zum Tod zu untersuchen. Der sogenannte „terminal drop“, also die Verringerung der kognitiven Leistung in den letzten Monaten vor dem Tod unabhängig vom chronologischen Alter, ist dafür ein Beispiel (Gerstorf, Ram, Roecke, Lindenberger, & Smith, 2008; Ghisletta, 2008; Thorvaldsson et al., 2008). Auch wenn die Prädiktion von Entwicklungsverläufen mit der Altersskalierung als Abstand zum Tod mehr Varianz aufklären kann, bleiben dies inhaltlich unterschiedliche Aspekte. So kann eine Person eine ganze Reihe von Aktivitäten unternehmen, die ihr angesichts drohender kognitiver Leistungsverluste das Überleben garantieren; dies sind aber nicht notwendigerweise dieselben Aktivitäten, die eine Person zugunsten der eigenen Weiterentwicklung oder im Hinblick auf die Weitergabe von Wissen an die folgende Generation unternimmt. Im extrem hohen Alter sind diese beiden Entwicklungsmechanismen zunehmend stärker konfundiert.

Eine fünfte Herausforderung liegt in der noch immer bestehenden Seltenheit von Personen im sehr hohen Alter und insbesondere der Seltenheit der Verfügbarkeit längsschnittlicher Daten. Um eine optimale Datenqualität zu erreichen, ist es wichtig, ein gutes Verhältnis zwischen Datentiefe und Datenbreite anzustreben. Dies bedeutet, ein Versuchsdesign aufzustellen, bei welchem vor Beginn der Studie feststeht, wie viele Daten zu einem Konstrukt erhoben werden (Datentiefe) und welche Konstrukte von Interesse sind (Datenbreite). Gerade bei Längsschnittstudien mit sehr alten Personen ist die optimale Wahl der Datentiefe und Datenbreite schwierig, da teilweise nur wenig Erhebungszeit pro Person zur Verfügung steht. Darüber hinaus sind Längsschnittstudien oft in erster Linie als Querschnittstudien geplant und es ergeben sich über die Zeit erst Fragestellungen, die durch die bestehende Datentiefe oder Datenbreite nicht geklärt werden können.

Eine Methode, die viele Möglichkeiten bietet, aber auch Schwächen aufweist, ist das Datenpooling, also die Nutzung von mehreren Datensätzen entweder zur Replikation von Zusammenhangsbefunden oder zur Zusammenführung in eine grössere Versuchspersonengruppe (Hofer & Piccinin, 2009). Durch das Zusammenführen von Datensätzen ergibt sich eine grössere Datenbank, welche mehr Versuchspersonen und demzufolge eine erhöhte Teststärke mit sich bringt. Dadurch können bereits kleinere Veränderungen entdeckt werden. Ein weiterer Vorteil kann darin liegen, dass verschiedene Stichproben zusammengelegt werden, was zu einer stärkeren Heterogenisierung führt und somit die Repräsentativität der Stichprobe erhöht. Eine umfassende, beispielhafte Datenbank von zurzeit 25 Längsschnittstudien bietet das Datennetzwerk von „Integrative Analysis of Longitudinal Studies of Aging (IALSA)“ an der University of Victoria (http://ialsa.uvic.ca/Plone/long-studies), einem internationalen Netzwerk von Längsschnittstudien aus den USA, Australien, Schweden, Deutschland und der Schweiz. Nachteile beim Datenpooling liegen in der Unterschiedlichkeit der Daten. Durch die unterschiedliche Durchführung der Studien, kann es sein, dass Daten miteinander verglichen werden, die nicht genau dasselbe messen. Beispielsweise können durch Abweichung in der durchführenden Sprache oder der Instruktion wesentliche Unterschiede auftreten, die eine Verzerrung der Daten zur Folge haben (Costafreda, 2009). Diese Verzerrungen sind je nach untersuchten Daten und Datensätzen als eher gering einzuschätzen, denn sonst könnten

Studienergebnisse aus Längsschnittstudien, wie es etablierte Praxis ist, kaum den Anspruch auf Generalisierbarkeit erheben, dass sich also die Ergebnisse replizieren lassen – ein Anspruch, der sich schon aus ökonomischen Gründen nicht jedes Mal neu testen lässt. Gerade beim Aufwand, der mit der Erhebung längsschnittlicher Daten verbunden ist, bietet die Nutzung vorhandener Daten eine wichtige Ergänzung des Methodenrepertoires. Denkbar ist beispielsweise, dass zukünftig vor neuen Studien dargelegt werden muss, dass die Untersuchungsfragen nicht mit bereits vorhandenen Längsschnittdatensätzen beantwortet werden können. Dies wäre etwa bei Untersuchungen der Fall, die die Zusammenhänge zwischen Veränderungen (nicht Unterschieden) in Lebensstilen mit Veränderungen in der Adaptivität kognitiver Leistungen im sehr hohen Alter untersuchen.

3.1.6 Fazit

Die Erforschung von adaptiven Prozessen im höchsten Alter bietet eine Reihe von Vorteilen für das Verständnis der Grenzen menschlicher Adaptationsprozesse, wenn die methodischen und theoretischen Herausforderungen adäquat gelöst werden können. Wir schlagen daher für die zukünftige psychologische Erforschung der Hochaltrigkeit zwei Schwerpunkte vor. Der erste Schwerpunkt sollte die Durchführung neuer längsschnittlicher Studien sein, die bei Personen im höchsten Alter die Prozesse untersuchen, die zur Stabilisierung von Autonomie und Lebensqualität eingesetzt werden. Da die bisherigen Daten im Wesentlichen aus Querschnittstudien oder Längsschnittstudien mit Messabständen von einem Jahr und mehr stammen, liegen bisher nur wenige Erkenntnisse über die adaptiven Potenziale und Plastizität des höchsten Alters vor. Dabei ist bisher offen, ob die Gruppe der Höchstaltrigen psychologische Eigenschaften aufweisen, die sie bereits in früheren Lebensphasen hatten (dies könnte man als Stabilitäts- oder Überlebens-Hypothese bezeichnen) oder ob es sich um eine Gruppe von Personen handelt, die sich gerade durch die

Veränderungsfähigkeit von Fähigkeiten und Eigenschaften auszeichnet, die ihnen erlaubt, mit den veränderten physiologischen, sozialen und psychologischen Bedingungen und Anforderungen des höchsten Alters auszukommen. Wir haben versucht darzulegen, dass gerade die Höchstaltrigen für die Beantwortung der Frage nach den Prozessen für eine optimale Orchestrierung von psychologischen Ressourcen bei jeweils niedriger Einzelressourcenlage prädestiniert sind. Erkenntnisse über die Möglichkeiten und Grenzen der Orchestrierungsleistung versprechen auch Angehörigen jüngerer Altersgruppen wertvolle Erkenntnisse für die Unterstützung und Moderation der Bewältigung kritischer Lebensereignisse und Erkrankungen ebenso wie der Lebensgestaltung und Sinnfindung.

Der zweite Schwerpunkt sollte in der Erarbeitung der methodischen und theoretischen Grundlagen der Nutzung vorhandener Daten über das höchste Alter liegen. Mit Wegen zur Definition der Vergleichbarkeit von wenigen Fällen extremer Hochaltrigkeit zwischen verschiedenen Datensätzen aus verschiedenen Ländern könnte die Teststärke für viele Fragestellungen deutlich erhöht werden. Dies ist allein schon deshalb bedeutsam, als hohe Teststärken insbesondere für den schlüssigen Nachweis der Stabilität kognitiver (und anderer) Leistungen darstellen (denn hier soll beispielsweise der Befund abgesichert werden, dass es *keinen* Unterschied zwischen 85- und 100-jährigen in der Lebensqualität oder der Lebenszufriedenheit gibt, weil es den Höchstaltrigen gelingt, ihre verringerten Ressourcen optimal zu orchestrieren). Gleichzeitig könnte die Lösung des Problems der Vergleichbarkeit von seltenen Hochaltrigkeitsphänomenen in der Anpassungsleistung ein Muster für die Untersuchung einer ganzen Reihe von anderen, ebenfalls seltenen Phänomenen des höchsten Alters zwischen verschiedenen Studien darstellen. Man denke in diesem Zusammenhang nur an die Seltenheit identischer Symptom-, Umwelt- und Betreuungskonstellationen bei demenziell Erkrankten (Moor, Waldner, & Schelling, 2010), aussergewöhnlich leistungsfähigen Höchstaltrigen oder an denLändervergleich in Entwicklungsverläufen nach Behandlungen.

Insgesamt steht die an Veränderungen, an Entwicklung und an Lebensgestaltung orientierte psychologische Erforschung des höchsten Alters erst an einem vielversprechenden Anfang und hat noch erhebliche methodische und theoretische Herausforderungen zu meistern. Sie verspricht jedoch nicht nur Erkenntnisse über die jetzt und zukünftigen Hochaltrigen, sondern Gewinne für ein Verständnis von ressourcenorientierter Entwicklung und deren Stützung durch geeignete und am Einzelfall orientierte Interventionen über die gesamte Lebensspanne. Sie hat die Chance zu einem Bild des Alters beizutragen, dass durch eine differenzierte Sicht auf die Grenzen der menschlichen Adaptationsfähigkeit geprägt ist und begreifbar macht, dass die menschliche Entwicklung lediglich in ihren Grenzen vorhergesagt werden kann, aber bis ins höchste Alter Gestaltungsspielräume bietet. Dabei ist der Blick auf (zumindest heute noch) seltene Phänomene der Höchstaltrigkeit gleichzeitig eine wichtige Übung in der Entwicklung individuenzentrierter Entwicklungsforschung.

3.2 Study 2: Potential Protection from Deficit through Educational and Intellectual Activities across the Lifespan[3]

3.2.1 Introduction

Average age differences and longitudinal age changes in cognitive development are well documented (for an overview see Craik & Salthouse, 2007). However, relatively little research exists on protective factors against cognitive decline in old age. Among the factors most prominently mentioned as potentially protective are education, intellectual engagement, and lifelong learning (Willis et al., 2009). In fact, Stern (Stern, 2002) even suggested that through education and intellectual engagement people can build up cognitive reserve to buffer brain pathology or brain lesions. This explains why people with higher levels of intelligence, higher education and greater vocational success are more likely to recover from a brain lesion (cf. Katzman, 1993). However, it is still unclear under which circumstances and to what degree education and intellectual activity influence the developmental trajectories of cognitive abilities in old age.

The literature on education and its influence on cognitive development in old age is inconsistent. Some studies have found a positive effect of education on cognitive development (cf. Baltes & Lindenberger, 1988; Hultsch et al., 1999) whereas others have not (H. Christensen, Henderson, Griffiths, & Levings, 1997). Further studies have emphasized that education has only a protective effect on certain cognitive abilities, namely the verbal abilities (H. Christensen et al., 1997; Gold et al., 1995). One reason for these equivocal findings may be the samples examined. For instance, whereas Hultsch et al. (1999) compared 487 community-dwelling adults aged between 55 and 86 (first measurement), H.

[3] A similar version of this chapter has been published in “Current Aging Science” (Schumacher & Martin, 2009a)

Christensen et al. (1997) examined 26 fellows of the Australian Academy of Humanities, Academyof Social Sciences and Academy of Science (mean age 75.8), 30 retired blue-collar workers (mean age 74.5) and 30 Ph.D. students from the Australian National University. Another reason for the equivocal findings may be the difficulty of controlling for similarity in lifestyles and intellectual activity. Typically, representative samples contain large interindividual differences in education, intellectual activities, social status or income.

Our study focuses on the behavioral cognitive plasticity in old age (Willis et al., 2009). We assume that very high levels of education and lifelong intellectual engagement may postpone average age-related changes in cognition and, thus, would predict smaller age differences compared to a less well-educated sample. Therefore, we compared age differences in an extremely well-educated sample of individuals typically highly engaged in intellectual activities throughout their lives, i.e., university professors, to age differences in a representative sample of old individuals covering the same age range.

Previous studies with professor samples conducted group comparisons of cognitive performance in an active, non-active or a combined sample of active and retired professors and normal comparison samples. They have consistently demonstrated an advantage of the well-educated professor samples in the encoding and retrieval of verbal material (Compton, Bachman, Brand, & Avet, 2000; Shimamura, Berry, Mangels, Rusting, & Jurica, 1995; Sward, 1945; Vanderaspoilden & Morais, 2001). However, in extension of these findings, if extremely high levels of education and intellectual engagement protects from cognitive decline, cross-sectional data should demonstrate smaller age-related differences in the professor compared to a normal comparison sample

Therefore, in the present study we examined professors from their retirement year onward (age range 65 to 80 years). As a comparison sample, the data of a representative sample of 65-80-year-olds was used (Zimprich et al., 2008). To assess if education has a positive effect on cognitive aging, we compared groups with respect to performance and age effects in cognitive measures typically found to be age sensitive, i.e. processing speed, working memory and cued and free recall (Park, 1999).

3.2.2 Methods

3.2.2.1 Sample.

In our study, we compared two samples, a representative and a highly educated professors' sample. The representative sample consisted of participants from the Zurich Longitudinal Study of Cognitive Aging (ZULU) (Zimprich et al., 2008) designed to be representative of older adults living in Switzerland. The participants of the highly educated sample were recruited on the basis of a complete list of all University of Zurich professors born after 1910 who had reached retirement age. To match the participants according to their age and gender, only male participants between the ages of 65 and 80 years were included in the analysis. Thus, the normally educated sample consisted of 196 participants (out of 364) and the highly educated sample of 62 participants (out of 86). When screened for dementia (Mini-Mental State Examination (MMSE); Folstein, Folstein, & Mchugh, 1975), no participant from the highly educated sample was at risk for dementia (threshold value 26), whereas two participants in the normally educated sample were (threshold value 24) (Crum, Anthony, Bassett, & Folstein, 1993). Those two were removed from the data analysis.

3.2.2.2 Materials and Procedure.

All participants, except one with a walking disability (who was tested at home), attended the test session at a centrally located testing site after signing the informed consent form. All participants were instructed and tested individually. Before starting the actual experiment, participants filled out questionnaires on sociodemographic information, the

MMSE, subjective health, and on their typical intellectual engagement (TIE; see below). Then each participant completed a cognitive test session lasting approximately 40 minutes, including story recall, paired-associates learning, a reading span task and a letter digit substitution test, all of which were computerized except for the story recall.

In our study, intellectual engagement was measured with the Typical Intellectual Engagement questionnaire (TIE) adapted from Dellenbach and Zimprich (Dellenbach & Zimprich, 2008). The instrument uses 17 items to measure the degree to which individuals prefer to engage in cognitively demanding or challenging leisure tasks and activities. It has a minimal score of 17 and a maximum score of 85 points, with a higher score implying that the person likes to be engaged in challenging leisure tasks. In our study Cronbach's alpha was between .58 and .81.

To measure episodic memory, story A of the Logical Memory subtest of the German version of the Wechsler Memory Scale-Revised (WMS-R) (Härtinger et al., 2000) was used. In this test, participants are instructed to listen closely to a story read aloud by the experimenter. Then the participants are asked to recall as many of the 25 semantically meaningful units as possible. Test-retest reliability of this test is .79 (Härtinger et al., 2000).

The paired-associates learning task consisted of 12 semantically unrelated word pairs of the German WMS-R and the Munich Verbal Memory Test (MVGT) (Ilmberger, 1988). After presentation of all 12 word pairs, only the first word of a pair appeared on the screen as a cue, and the second was replaced by a question mark (e.g., salad - ?), using a different order than that used during encoding. For each cue presented, participants were asked to recall the associated target word. Test-retest reliability for the WMS-R is .78 (Härtinger et al., 2000).

To asses working memory, a modified version of the reading span task by Daneman and Carpenter (Daneman & Carpenter, 1980) was utilized. In this test, participants are asked to read sentences aloud and to decide if the sentence was meaningful or not by pressing designated keys on the computer keyboard. Furthermore, participants were instructed to memorize the last word of each sentence. After several sentences, three question marks appeared on the screen, indicating that the participant should name the memorized words in the same order as they had been presented. The dependent variable was the average percentage of items recalled in correct order (Conway et al., 2005), and test-retest reliability is .76 (Friedman & Miyake, 2004).

Finally, participants had to perform a letter digit substitution task which was similar to the well-known Digit Symbol Substitution task, except that participants were required to assign digits to letters instead of symbols to digits. For each item, there was a different coding table and a new cue letter in order to reduce memory influences (Piccinin & Rabbitt, 1999). After two practice items, participants had 90 seconds to work on the task. Test-retest reliability is .88 (Houx et al., 2002). All cognitive tests used in our study are described in more detail in Zimprich et al. (2008).

3.2.2.3 Statistics.

The Kolmogorov-Smirnov test revealed that while the test results in the paired-associates learning test were nonparametric they were parametric in all the other cognitive tests. Differences in the mean values of the different cognitive tests were either assessed by *t*-test (parametric data) or by Mann-Whitney U test (nonparametric data). To consider the sample differences concerning the principle variables, the Hotelling's T^2 was utilized. Furthermore, to locate age effects in the two samples, either Pearson correlations (parametric data) or Spearman correlations (nonparametric data) were performed. To test whether the correlations differed significantly between the two groups, Fisher's z-transformation was utilized.

3.2.3 Results

Table 2 presents the mean values and the standard deviations for the sociodemographic variables, subjective health, typical intellectual engagement, and cognitive test scores of the highly educated and normally educated samples. As expected, the groups did differ in their formal education, typical intellectual engagement and income, but not in their subjective health and age (see Table 2).

Independent-sample *t*-tests and Mann-Whitney U tests were conducted to compare the test results in story recall, paired associates, the reading span task and the letter digit substitution test in the normally and highly educated sample. While the highly educated participants performed on average significantly better in the paired associates ($z = -2.55$, $p < .05$, $r = 0.40$) and the reading span tasks ($t(256) = 7.82$, $p < .001$, $d = 1.14$) than the normally educated participants, this was not the case in the story recall ($t(256) = .07$, $d = 0.01$) and the letter substitution tests ($t(256) = 0.11$, $d = 0.02$). Furthermore, to consider the differences of the means between the two samples, a Hotelling's T^2-test ($F(4, 253) = 16.02$, $p < .001$) demonstrated that overall the means of the two samples were not equal.

To test the hypothesis whether very high levels of education and lifelong intellectual engagement may eliminate average age-related differences in cognition, we calculated correlations between age and the different cognitive tests within the two samples. As illustrated in Table 3, in both samples there was no significant relation between age and story recall and age and the reading span task. However, a lower performance in the letter digit substitution test was associated with higher age in both samples. Higher age was significantly related to lower performance in the paired-associates learning test only in the normally educated sample. In contrast, in the highly educated sample, there was a tendency for age to be positively correlated with performance in paired-associates learning. Furthermore, we used a Fisher's z-transformation to test whether the correlations of age and paired-associates learning differed significantly between the two samples. The results demonstrated that there is a significant difference between the correlations between the samples (z = 3.07, p < .01).

Based on these results, it cannot be established that the better performance in paired-associates learning of the highly educated samples was more likely due to a longer maintenance of the cognitive ability or to a higher starting level. If, however, the younger participants of the highly educated sample had the same starting level in the paired-associates learning test as the younger participants in the normally educated sample, this would suggest that individuals in the highly educated sample might be resistant to age effects for a longer time, but not that high education per se would lead to an increase in paired-associates scores. To answer this question, we split both samples into two age groups. Thus the cognitive test scores of the 65- to 72- year-olds of the normally educated sample were compared to the test scores of the 65- to 72-year-olds of the highly educated sample, and the same was done with the 73- to 80-year-olds. The results demonstrated that while the test score in the paired-associates learning test did not differ significantly between the 65- to 72-year-old adults of the normally and highly educated sample (z = -0.32, r = 0.01), they did differ between the 73- and 80-year-olds (z = -3.14, p < .01, r = 0.88). This is an indication that the effects of extremely high levels of education only appear in older ages. Concerning the other cognitive tests, the effects remained stable over the different age groups, i.e., when there was no difference in the means of the test results between the younger age groups of the normally and highly educated sample, there was also no difference to be found in the older age groups of the two samples (story recall, digit letter substitution test) and when there was a difference between the two samples (reading span task) there was also a difference to be found in the older age groups of the two samples.

Table 2

Mean +/- SD Test Scores of Sociodemographics, Health, and Cognitive Performance

	Education			
	High (N=62)		Normal (N=196)	
Varible	Mean	SD	Mean	SD
Age	72.47	±4.02	73.04	±4.41
Subjective health	5.03	±0.72	4.85	±0.78
Income	6.97	±0.18	5.11	±1.65***
Education (years)	20.61	±2.26	13.69	±2.97***
TIE sum score	66.58	±6.38	57.03	±10.09***
Story recall	14.26	±3.47	13.92	±4.28
Paired-associates	3.81	±2.86	2.76	±2.15**
Reading span	0.77	±0.14	0.59	±0.16***
Letter digit	33.10	±5.92	31.83	±6.89

*p < .05, **p < .01, ***p < .001

Table 3

Correlation of Cognitive Test Scores with Age

	Education	
	High (N=62)	Normal (N=196)
Story recall	-.11	-.08
Paired-associates	.18	-.27**
Reading span	.03	.00
Letter digit	-.41**	-.34**

*p < .05, **p < .01, ***p < .001

[a] 1 < 2000 CHF, 2 = 2000CHF - 3000CHF, 3 = 3000CHF - 4000CHF, 4 = 4000CHF - 600CHF, 5 = 6000CHF - 8000CHF, 6 = 8000CHF - 10000CHF, 7 > 10000CHF

3.2.4 Discussion

The main goal of this study was to compare the age differences in cognitive performance in a sample of normally and a sample of highly educated older adults. First of all, our results replicate earlier findings that highly educated adults tend to outperform normally educated adults in verbal tasks. It has to be noticed, however, that in our study this is only the case for two verbal tasks out of three, namely paired-associates learning and reading span. Furthermore, when the samples were stratified for age, the sample differences in the paired- associates learning test disappeared between the 65- to 72-year-olds. This suggests that the advantages of extremely high levels of education may only start to appear in older age. In contrast, in the working memory task extremely high level of education was related to better performance across the complete age range.

It has to be noted that a lack of sample differences may be due to a particularly high performance comparison sample. For instance, in our study normally educated adults performed equally well as highly educated adults when they had to recall a story. This is different from the findings of Shimamura et al. (1995), who did the same story recall test with an American sample. While in their study the professors retrieved approximately 54 percent of the story and the non-professors 42.5, in our study the highly educated sample recalled 57 percent in contrast to 55.7 percent of the normally educated sample.

In any case, the main goal of our study was to test whether very high levels of education may reduce average age-related differences in cognition. There was an age effect for the speed measure of letter digit substitution, but no difference in the age effect between the samples. The age effect is not surprising, since speed is one of the most age sensitive variables (cf. Salthouse, 1996), and education may have only a small influence on its developmental trajectory. The age effect on speed of processing has also been demonstrated in other studies with a professor sample (cf. Shimamura et al., 1995; Sward, 1945). There were no age effects for verbal working memory and verbal memory (except in the paired-associates learning test), and no differences in the age effects between the groups. On the one hand this is good news, because it suggests a stable level of essential memory performances even in normally educated samples. On the other hand, it is difficult to interpret without a longitudinal follow-up. Since we have used cognitive performance measures that have reliably shown age effects, but did not observe age associated deficits, it is unclear why this is the case. It is unlikely that the lack of age effects is due to selection effects, because then we should have found no age-related differences in speed. It might be the case that education only emerges as a predictor with performance dropping below a certain threshold, or that intellectual engagement can help to compensate for declines in both samples, or that the normal samples had a higher level of intellectual engagement compensating for lower levels of education.

Most interestingly, there was an age effect in the normally educated adults in the paired-associates learning task, but not in the highly educated adults. Although the younger adults in both samples had the same starting level in this cognitive task, there was a significant difference in the older adults. This suggests that while age had an effect on the test score in the normally educated sample, the test results of the highly educated sample stayed unaffected of age. On the one hand, this finding suggests that education may protect from age-associated deficits specifically in paired-associates learning. On the other hand, the results also suggest that education may not make immune against age deficits, but that it postpones the processes eventually leading to these deficits. Only longitudinal data will make it possible to determine the influence of extremely high levels of education on the development of paired-associates learning, but the current cross-sectional data do reveal that the highly educated adults tend to have some kind of educational benefit that affects the age correlated deficits in the paired-associates learning task positively.

Overall, this study presents an important overview on cognitive abilities of 65- to 80-year-olds. It must be noted that comparing extremely highly educated aged individuals with representative samples of old adults allows us to examine age effects in old age that are not distorted by cohort differences in education and lifestyle. However, such a selection of samples can cause problems. The data cannot easily be generalized to the general population. Moreover, due to the research design, a self-selection may have taken place even within the professors’ sample so that they might be even more selective with respect to health and motivation to participate. Notwithstanding, the findings of our study indicate that some deficits, which were hitherto associated with chronological age, are more likely a result of other influences or occur under certain circumstances only in very old age. The data suggests that education and lifelong intellectual engagement can influence test performance to such an extent that age deficits in paired-associates learning might completely disappear in 65- to 80-year-olds. If it is not age which most influences cognitive development, it might be possible to influence the process of cognitive development more than initially thought. Whether this is truly the case or not, however, can only be determined by conducting longitudinal follow-up studies which consider the individual development of cognitive abilities and examine the role of self-selection in the study on the effects of education and intellectual engagement on cognitive aging. When these data are available and demonstrate promising results, the next step will be to investigate suitable trainings and interventions to minimize the difference of the cognitive age deficits between highly and normally educated adults.

3.3 Study 3: Simultaneously measuring gait and cognitive performance in cognitively healthy vs. cognitively impaired older adults4

3.3.1 Introduction

Many tasks of daily life require the simultaneous performance of multiple tasks, which often require both motor activity and memory. With advancing age, the ability to divide attention and to perform multiple tasks simultaneously seems to be impaired (Singer, Verhaeghen, Ghisletta, Lindenberger, & Baltes, 2003; Verhaeghen & Cerella, 2002). Particularly, when individuals have motor or cognitive impairments, it is more difficult for them to perform concurrent motor and cognitive tasks. Performance in one or both tasks may have to be adapted in order to execute both tasks simultaneously. Therefore, it is of great interest and importance to investigate motor activities such as gait in the presence of additional attention-demanding cognitive tasks. Gait is a process that requires attention, planning and memory (Hausdorff, Yogev, Springer, Simon, & Giladi, 2005; Mulder & Hochstenbach, 2003; Woollacott & Shumway-Cook, 2002), and hence can be affected by attention-demanding tasks. According to Verhaeghen and Cerella (2002) older adults require more attention to maintain stable gait. Usually, when older individuals are asked to walk and simultaneously perform another task, they walk more slowly. Moreover, gait disturbances are especially common in individuals with cognitive impairment (Gillain et al., 2009; Maquet et al., 2010; Persad, Jones, Ashton-Miller, Alexander, & Giordani, 2008; Sheridan, Solomont, Kowall, & Hausdorff, 2003). These findings are of particular importance given that abnormal gait is a strong predictor of future falls, institutionalization, and even death (Bloem, Steijns,

[4] A similar version of this chapter has been published in “Journal of the American Geriatrics Society” (Theill, Martin, Schumacher, Bridenbaugh, & Kressig, 2011)

& Smits-Engelsman, 2003; Hausdorff, Rios, & Edelberg, 2001; Hausdorff, Yogev, Springer, Simon, & Giladi, 2005; Springer et al., 2006; Verghese et al., 2006).

In the current study, we investigated the interaction of gait and cognition in older individuals with and without cognitive impairment using a dual-task paradigm consisting of a working and a semantic memory task. Both tasks were already utilized to demonstrate dual-task-related gait impairment in older adults with and without cognitive impairment (Beauchet et al., 2007; Beauchet, Dubost, Aminian, Gonthier, & Kressig, 2005; Beauchet, Dubost, Gonthier, & Kressig, 2005; Dubost et al., 2006; Hausdorff, Schweiger, Herman, Yogev-Seligmann, & Giladi, 2008; Montero-Odasso et al., 2009; Priest, Salamon, & Hollman, 2008; Sheridan, Solomont, Kowall, & Hausdorff, 2003; Springer et al., 2006; Srygley, Mirelman, Herman, Giladi, & Hausdorff, 2009; van Iersel, Ribbers, Munneke, Borm, & Rikkert, 2007). However, only few studies investigated gait under dual-task conditions comparing older adults depending on their state of cognitive impairment (Gillain et al., 2009; Maquet et al., 2010; Sheridan, Solomont, Kowall, & Hausdorff, 2003). Cognitively impaired older adults seem to have a lower gait velocity compared to individuals that are cognitively less impaired or healthy (Gillain et al., 2009; Maquet et al., 2010; Sheridan, Solomont, Kowall, & Hausdorff, 2003).

Most previous studies on motor-cognition dual-task performance investigated only gait parameters such as velocity (Beauchet, Dubost, Aminian, Gonthier, & Kressig, 2005; Beauchet, Dubost, Gonthier, & Kressig, 2005; Dubost et al., 2006; Hausdorff, Schweiger, Herman, Yogev-Seligmann, & Giladi, 2008; Montero-Odasso et al., 2009; Priest, Salamon, & Hollman, 2008; Sheridan, Solomont, Kowall, & Hausdorff, 2003; Springer et al., 2006; Srygley, Mirelman, Herman, Giladi, & Hausdorff, 2009; van Iersel, Ribbers, Munneke, Borm, & Rikkert, 2007). We additionally analyzed changes in cognitive performance between single and dual-task conditions, which to our knowledge has not been done so far.

By investigating both motor and cognitive performance, it is possible to evaluate if and to what extent the individuals are able to walk and simultaneously perform an additional cognitive task, as well as which performance is more impaired in general and with increasing cognitive impairment. For example, some may adapt to the task and the single ability decrements by reducing gait velocity, some by reducing gait regularity, some by producing more cognitive errors, and some with a combination of the adaptive adjustments. With a working and a semantic memory task we used two different types of cognitive tasks to examine whether there are task-specific dual-task effects on gait and on cognitive performance. According to the literature there seems to be no task-specific gait changes during dual-task walking, at least with regard to gait velocity (Beauchet, Dubost, Gonthier, & Kressig, 2005; Bloem, Steijns, & Smits-Engelsman, 2003; Montero-Odasso et al., 2009; O'Shea, Morris, & Iansek, 2002). However, little is known whether there are task-specific effects on cognitive performance during dual-tasks.

We hypothesized that the participants would not only reduce their gait velocity but also perform worse in both memory tasks during dual-task conditions and that such dual-task interference would be greater in those with cognitive impairments. Additionally, we investigated whether the performance changes during the dual-task condition are greater in gait or in cognitive performance and if there are performance differences between the different memory tasks or between cognitively healthy older and cognitively impaired older individuals.

3.3.2 Methods

3.3.2.1 Participants.

From the 894 older adults tested, 711 (mean age 77.22 (± 6.24), age range 65-97, 49.2% women) were included in this analysis. The sample consisted of 419 outpatients from the Basel Memory Clinic and 292 participants from the Basel Study on the Elderly (Project BASEL). The project was approved by the local Ethics Committee. Participants were excluded if they had severe medical, psychiatric or neurological conditions that could impair their cognitive ability or gait such as Parkinson's disease or major depression, or if they suffered from severe dementia (Mini-Mental State Examination < 16; Folstein, Folstein, & McHugh, 1975). Participants with walking aids were excluded unless they were able to accomplish the task without using their walking aid. Furthermore, only participants were included whose answers were explicit without any interpretational bias such as translation problems or ambiguous corrections during the working memory task. Cognitive impairment was defined as a score of less than 25 points in the Mini Mental State Examination (MMSE) (Folstein, Folstein, & McHugh, 1975). Of the sample, 548 (77.1%) participants had an MMSE score greater than 24 and were categorized as cognitively healthy, 163 (22.9%) participants had an MMSE score between 16 and 24, and were categorized as cognitively impaired. The mean MMSE score was 26.66 (± 3.13) with a range from 16 to 30. All group characteristics are listed in Table 4.

3.3.2.2 Instruments for gait.

Gait analyses were performed according to the European guidelines for clinical applications of spatio-temporal gait analysis in older adults (Kressig & Beauchet, 2006) using the GAITRite® system (GAITRite® Gold, CIR Systems, PA, USA). This system consists of a

972cm-long electronic walkway with integrated pressure sensors placed every 1.27cm over an active electronic surface area of 792 x 610cm, giving a total of 29,952 sensors. The scanning frequency was 60Hz. Data from the mechanically activated sensors are collected by onboard processors and transferred via cable and serial port to a computer and analyzed with the GAITRite® software version 3.8. The walkway is flanked at the beginning and end by 1.25m-long electronically inactive walkway sections. Acceleration and deceleration phases of gait occur on these electronically inactive sections, ensuring measurement of gait parameters under steady state conditions.

3.3.2.3 Testing procedure.

Before each gait analysis, participants were asked about their medical conditions, medications, fall history and the current use of walking, vision, or hearing aids. Subsequently, participants were verbally instructed regarding the gait analysis test procedure. A demonstration followed if the verbal instructions were not understood. No practice walks were performed before testing. Participants wore their normal shoes and a safety belt, and were accompanied by the test administrator for each walk.

Participants were instructed to complete one trial each of the following consecutive walking trials: self-selected speed (“normal walking”), self-selected speed while performing the working memory dual-task (counting backwards out loud from 50 by 2s) and self-selected speed while performing the semantic memory dual-task (enumerating animals out loud). Previous studies have typically used rather demanding working memory tasks (Hausdorff, Schweiger, Herman, Yogev-Seligmann, & Giladi, 2008; Priest, Salamon, & Hollman, 2008; Springer et al., 2006; Srygley, Mirelman, Herman, Giladi, & Hausdorff, 2009; van Iersel, Ribbers, Munneke, Borm, & Rikkert, 2007). However, with increasing difficulty, even healthy older adults tend to either neglect the additional tasks or prioritize the walking task

(K. Z. H. Li, Lindenberger, Freund, & Baltes, 2001; Salthouse, Hambrick, Lukas, & Dell, 1996). For this reason, we used a relatively simple working memory task (serial subtraction by 2s) in the current study. Hence, the task should allow even cognitively impaired individuals to successfully divide their attention in order to simultaneously complete both tasks.

For the dual-tasks, participants were instructed to perform both tasks simultaneously, no task priorities were given. The order of the dual-tasks was counterbalanced to avoid practice effects. Time needed for the dual-tasks was measured in seconds. This time was used for the same cognitive task performed while seated (cognitive single-task). All participants of the current sample were able to perform the working memory as well as semantic memory dual-task independent of their cognitive status.

3.3.2.4. Analysis procedures.

Gait velocity was normalized with height (cm/sec divided by height in meters) because of the potential height-dependent differences. For the working memory task the correct calculations backwards were counted as well as the number of calculation errors and repetitions. For the semantic memory task the total number of animals named, errors and repetitions were counted, whereby errors were defined as any word that was not an animal. Because of the greater chance to produce more correct calculations, animal names or errors and repetitions with more time, scores from the working and semantic memory tasks were normalized with the time required to complete the tasks (number of calculation, animal names and error/repetitions divided by time). Decrements of performance from single to dual-task were represented by relative changes of the normalized scores.

3.3.2.5 Statistical analysis.

Distribution assumption of the data was verified looking at distribution histograms and values of skewness or kurtosis. In cases where approximate normal distribution was violated, nonparametric tests were used. The data from gait analysis as well as the performance of the working and semantic memory tasks were subjected to analysis of variance (ANOVAS) or to analysis of covariance (ANCOVAS) for repeated measures with the single and dual-task performance as within subject factors, the group variable as between subject factor, and possible confounders as covariates or Man Whitney *U* respectively Friedman test in cases where normal distribution was not given. Scores of MMSE, age and number of psychoactive drugs per day were considered as confounding variables when analyzing gait velocity. Education in years was additionally considered when investigating the cognitive performance of the memory tasks. This allows a better comparability between the cognitively healthy and the cognitively impaired individuals, since the two groups showed a significant difference in these variables (Table 4). Significance values reported are based on effects before and after controlling for confounders to allow an estimation of their influence on the findings.

For the comparison of the number of individuals reducing gait velocity or cognitive performance during dual-task between the cognitively impaired and the cognitively healthy group, the participants were split into groups of those who decreased and those who increased their gait velocity or cognitive performance, which were then analyzed using chi square test.

In order to compare decrements of gait velocity and cognitive performance, relative performance changes in percentage from single to dual-task were calculated and subjected to ANOVA and ANCOVA for repeated measures, using the confounding variables mentioned above as covariates. The two-tailed level of significance was set at $p < .05$. All statistics were calculated using SPSS 18 for Macintosh.

Table 4

Mean +/- SD Test Scores of Sociodemographics of the Two Groups

Variable	All (n=711)	Cognitive status Healthy (n= 548)	 Impaired (n= 163)	*P*
Gender, n (%)				.040
Male	361 (50.8%)	290 (52.9%)	71 (43.6%)	
Female	350 (49.2%)	258 (47.1%)	92 (56.4%)	
Age	77.22 ± 6.24	76.56 ± 6.27	79.43 ± 5.58	< .001
MMSE	26.66 ± 3.13	28.10 ± 1.63	21.84 ± 1.86	< .001
Drugs[a]	3.55 ± 2.45	3.54 ± 2.40	3.60 ± 2.56	.798
Psychoactive drugs[a]	0.29 ± 0.62	0.23 ± 0.59	0.47 ± 0.80	< .001
Education (years)	12.04 ± 2.82	12.30 ± 2.83	11.28 ± 2.70	< .001
Previous falls				.715
Yes	288 (41.4%)	219 (41%)	69 (42.9%)	
No	407 (58.6%)	315 (59%)	92 (57.1%)	
Walking aid				.068
Yes	46 (6.5%)	30 (5.5%)	16 (9.8%)	
No	665 (93.5%)	518 (94.5%)	147 (91.2%)	

[a] Drugs per day

3.3.3 Results

3.3.3.1 Dual-task gait velocity.

Gait velocity was significantly lower in both the working memory (F (1,704) = 725.75, p < .001, η^2 = .508) and the semantic memory dual-task conditions (F (1,704) = 1080.13, p < .001, η^2 = .605) compared to the normal walking single condition (Table 5). However, 12.6% of the participants even increased their gait velocity during the working memory dual-task condition and 6.2% during the semantic memory task condition (defined as difference in velocity between dual and single-task of < 0). Additionally, gait velocity during the semantic memory task was significantly lower than during the working memory task (F (1,704) = 162.47, p < .001, η^2 = .188). The latter result was, however, no longer significant after adjustment for confounders.

Table 5

Mean Values (± SD) of Relative Gait Velocity during Single-task (ST) and Dual-task (DT)

Relative gait velocity (cm/sec)*	Single-task	Dual-task		*p* Single vs. Dual	
		WM	SM	WM	SM
All (n=711)	68.36 ± 13.13	55.53 ± 16.55	50.61 ± 17.12	< .001	< .001
Cognitively healthy (n=548)	70.03 ± 12.60	58.62 ± 15.56	53.19 ± 16.29	< .001	< .001
Cognitively impaired (n=163)	62.62 ± 13.34	44.90 ± 15.41	41.75 ± 17.01	< .001	< .001

* normalized with height (m)

† based on ANOVA for repeated measures

3.3.3.2 Dual-task cognitive performance of working and semantic memory tasks.

Compared to the single-task condition, participants made fewer correct calculations backwards during the working memory dual-task (F (1,691) = 518.10, p < .001, η^2 = .428). Overall, 76.4% of them made fewer correct calculations, 10.6% improved their performance and 13% of participants showed no differences between the single and dual-task performance. The effect was still significant after controlling for confounders (p < .05). During the semantic memory dual-task, the participants enumerated significantly fewer animal names (F (1,689) = 6.40, p = .012, η^2 = .009), but this effect disappeared after controlling for confounders. These results were reflected in 44.1% of the participants decreasing their performance of naming animals, whereas 34.4% increased their performance and 21.5% were unchanged. On the other hand, the dual-task condition had no effect on error or repetition rate in both cognitive tasks (p > .10). Values of cognitive performance are displayed in Table 6.

Table 6

Mean Values (± SD) of Cognitive Performance during Working and Semantic Memory Single and Dual-task, Normalized with Time Spent for Dual-task

	Single-task	Dual-task	*p*
Working memory task Correct calculation per second			
All (n=711)	0.76 ± 0.28	0.63 ± 0.24	< .001*
Cognitively healthy (n = 548)	0.83 ± 0.24	0.67 ± 0.22	< .001*
Cognitively impaired (n= 163)	0.53 ± 0.26	0.44 ± 0.23	< .001*
Working memory task Errors and repetitions per second			
All (n=711)	0.026 ± 0.070	0.029 ± 0.090	.695†
Cognitively healthy (n = 548)	0.018 ± 0.058	0.024 ± 0.088	.919†
Cognitively impaired (n= 163)	0.052 ± 0.098	0.046 ± 0.093	.622†
Semantic memory task Animal names per second			
All (n=711)	0.53 ± 0.22	0.52 ± 0.22	.012*
Cognitively healthy (n = 548)	0.58 ± 0.20	0.57 ± 0.20	.027*
Cognitively impaired (n= 163)	0.35 ± 0.18	0.34 ± 0.17	.209*
Semantic memory task Errors and repetitions per second			
All (n=711)	0.010 ± 0.027	0.011 ± 0.035	.107†
Cognitively healthy (n = 548)	0.007 ± 0.024	0.011 ± 0.035	.023†
Cognitively impaired (n= 163)	0.016 ± 0.033	0.014 ± 0.030	.674†

* based on ANOVA for repeated measures

† based on Friedman Test

3.3.3.3 Comparison of cognitively healthy and cognitively impaired individuals.

Gait velocity of the cognitively impaired individuals was lower in the single walking condition as well as in both dual-task conditions ($p < .01$) compared to the cognitively healthy individuals (Figure 3). During the working memory task, significantly more of the cognitively impaired individuals (93.6%) reduced their gait velocity compared to the cognitively healthy (χ^2 (1) = 7.47, p = .006), of whom 85.5% walked slower. Furthermore, there was a significantly greater reduction of gait velocity during the dual working memory task in cognitively impaired individuals (F (1,703) = 32.04, $p < .001$, $\eta^2 = .044$) with both a main effect for dual-task condition (F (1,703) = 682.01, $p < .001$, $\eta^2 = .492$) and for group (F (1,703) = 83.90, $p < .001$, $\eta^2 = .107$). These effects remained significant after adjustment for the confounding variables mentioned above ($p < .01$). During the semantic memory dual-task, there was no difference in the number of participants who walked slower or faster between the two groups (p = .474), but the cognitively impaired individuals reduced their velocity more than cognitively healthy individuals (F (1,703) = 9.83, p = .002, $\eta^2 = .014$). Additionally, there was a main effect for the dual-task condition (F (1,703) = 862.24, $p < .001$, $\eta^2 = .551$) and for group (F (1,703) = 65.81, $p < .001$, $\eta^2 = .086$). Again, the results remained significant after controlling for confounders ($p < .01$).

Cognitively impaired individuals generally made fewer correct calculations and committed more errors and repetitions during both working memory single and dual-tasks compared to cognitively healthy individuals ($p < .001$). They also produced fewer animal names during the semantic memory single as well as dual-task ($p < .001$) and committed more errors and repetitions in both conditions ($p < .05$).

As indicated in Figure 4, only the number of correct calculations backwards significantly changed from single to dual-task condition, at least when controlling for confounders. Interestingly, cognitively healthy individuals showed a greater decrease in their cognitive performance in the form of calculation backwards than cognitively impaired individuals (F (1,690) = 20.84, p < .001, η^2 = .029), which was still significant after adjustment for confounders (p < .001). Only 66.2% of the cognitively impaired individuals decreased their cognitive performance during the working memory dual-task compared to 79.3% of the cognitively healthy individuals. Moreover, 20.3% of the cognitively impaired individuals even increased their performance compared with 7.9% of the cognitively healthy individuals, which represents a significant difference (χ^2 (1) = 19.31, p < .001). On the other hand, the two groups did not show any difference in improvement or decline during the semantic memory task and there was no difference in reduction of number of animals named between the two groups (p > .05).

3.3.3.4 Gait velocity and memory task performance.

Generally, 66.5 % of the participants walked slower and performed worse cognitively during the working memory dual-task, whereas only 0.9% increased their gait velocity as well as their cognitive performance. During the semantic memory dual-task, only 41.8% showed decrements in both gait and cognitive performance and 2.8% showed an increase. One third of the participants decreased either gait velocity or cognitive performance while increasing the other performance at the same time. However, there was no difference between those walking slower or faster and their direction of performance change during dual-task, independent of their cognitive status (p > .10).

3.3.3.5 Comparison between cognitive performance of working / semantic memory task and gait velocity.

Since there was no change in the number of errors and repetitions made during single versus dual-task, only decrements of gait velocity and cognitive performance in the form of correct calculations and number of animals named were compared. During the working memory dual-task, the relative reduction of gait velocity and the number of correct calculations backwards did not differ (p = .935). On the other hand, during the semantic memory dual-task, the participants reduced their gait velocity more than their cognitive performance (F (1,673) = 357.75, p < .001, η^2 = .347). The reduction of gait velocity was greater during the semantic memory than the working memory dual-task (F (1,704) = 164.27, p < .001, η^2 = .189), whereas the decrease in cognitive performance was greater for the working memory than the semantic memory dual-task (F (1,635) = 165.32, p < .001, η^2 = .207). However, only the reduction of gait velocity still remained significant after adjustment for confounders (p < .05).

There was a significant interaction between relative performance change and group during the working memory dual-task (F (1,660) = 19.15, p < .001, η^2 = .028) with only a small main effect for the type of task performance (F (1,660) = 6.17, p = .013, η^2 = .009) and a main effect for group (F (1,660) = 16.32, p < .001, η^2 = .024). Cognitively healthy individuals therefore decreased their cognitive performance more than their gait velocity, whereas cognitively impaired individuals decreased their gait velocity more than their cognitive performance. The interaction was still significant after adjustment for confounding variables (p < .001). On the other hand, during the semantic memory dual-task both groups showed a greater decline of gait velocity than of cognitive performance (F (1,672) = 312.68, p < .001, η^2 = .318).

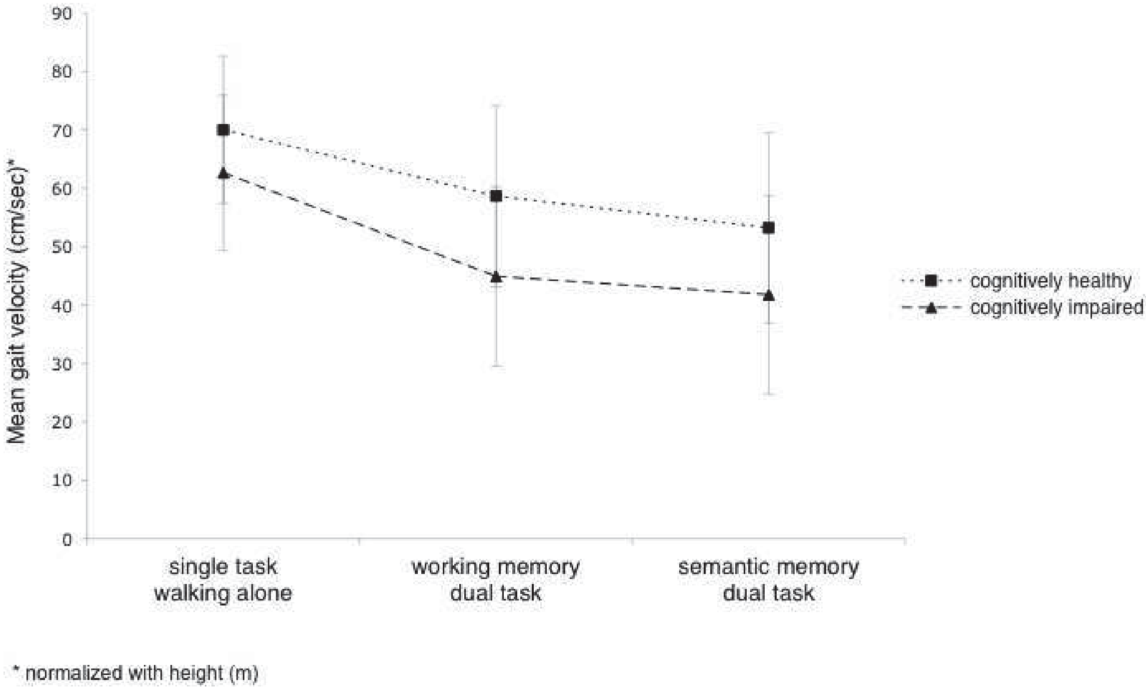

Figure 3. Mean gait velocity (normalized for height) of cognitively healthy (n= 548) and cognitively impaired individuals (n = 163) during single and dual-tasks. Both groups decreased their gait velocity during the working as well as during the semantic memory task ($p < .001$). Velocity of cognitively impaired individuals was lower in all the three conditions ($p < .01$). Additionally, cognitively impaired individuals decreased their velocity during both working and semantic memory tasks more than cognitively healthy individuals ($p < .01$). Error bars represent standard deviation.

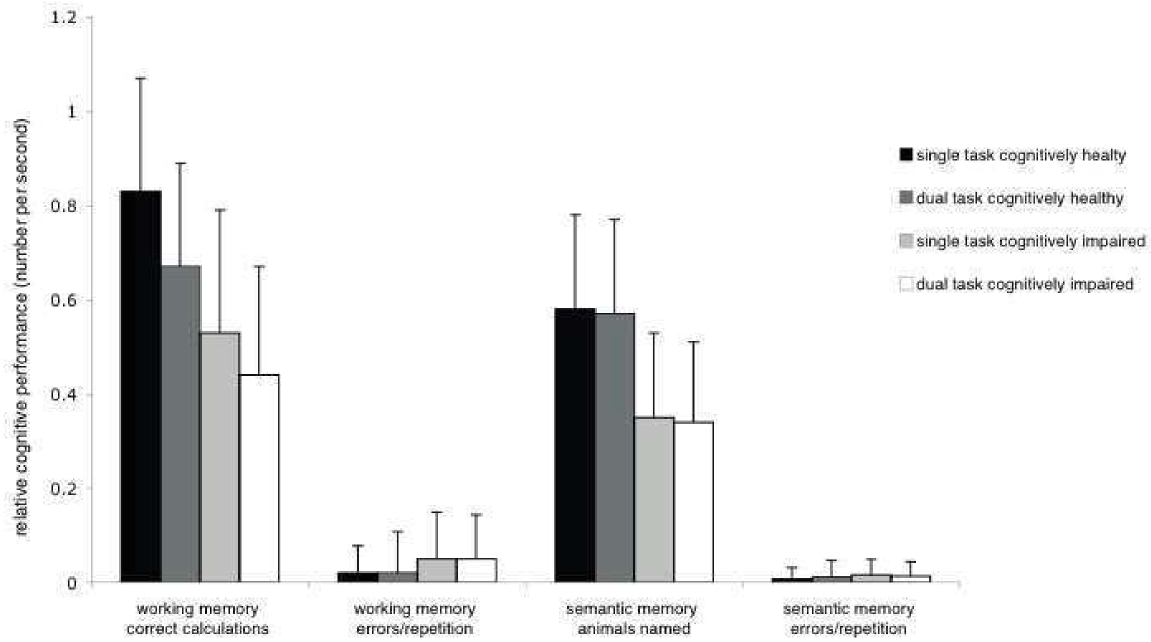

Figure 4. Single and dual-task performance of cognitively healthy (n = 548) and cognitively impaired individuals (n = 163). Both groups produced significantly fewer correct calculations ($p < .001$) during dual than single-task conditions, but did not produce more animal names and did not make more errors or repetitions during both dual-tasks ($p > .05$). Cognitively impaired individuals produced fewer correct calculations and animal names and made more errors and repetitions than cognitively healthy individuals ($p < .05$). Whereas the decrease in cognitive performance from single to dual semantic memory task did not differ between the two groups ($p = .844$), cognitively healthy individuals showed a greater decrease of cognitive performance in the working memory dual-task ($p < .001$). Error bars represent standard deviation.

3.3.4 Discussion

The goal of our study was to investigate motor-cognitive dual-task performance of older adults with and without cognitive impairment with regard to gait velocity as well as to task-specific cognitive performance.

During both dual-task conditions, the participants reduced their gait velocity compared to their gait speed while walking alone as a single-task. These findings are consistent with results reported from previous studies investigating dual-task gait performance in older adults with and without cognitive impairment (Beauchet, Dubost, Aminian, Gonthier, & Kressig, 2005; Beauchet, Dubost, Gonthier, & Kressig, 2005; Dubost et al., 2006; Hausdorff, Schweiger, Herman, Yogev-Seligmann, & Giladi, 2008; Montero-Odasso et al., 2009; Priest, Salamon, & Hollman, 2008; Sheridan, Solomont, Kowall, & Hausdorff, 2003; Springer et al., 2006; Srygley, Mirelman, Herman, Giladi, & Hausdorff, 2009; van Iersel, Ribbers, Munneke, Borm, & Rikkert, 2007). The reduction of gait velocity from single to dual-task was greater during the semantic memory task than the working memory task. However, previous studies could not find any difference in gait velocity or velocity change from single to dual-task condition between different types of dual-tasks (Beauchet, Dubost, Gonthier, & Kressig, 2005; Montero-Odasso et al., 2009; O'Shea, Morris, & Iansek, 2002).

In the current study, we additionally investigated the change in cognitive performance under dual-task conditions. Whereas participants performed worse in the working memory task under dual-task condition, their performance in the semantic memory task remained stable regardless of single or dual-task condition. There were, however, more individual differences during the semantic memory task with less than the half of the participants performing worse and at least a third performing even better during the dual compared to the single-task. By way of comparison, only one out of ten performed better during working memory dual-task. Interestingly, the participants did not make more errors or repetitions in either of the cognitive dual-task conditions. Therefore, there seems to be a negative impact of dual-tasking on productivity but not on error rate. The more demanding of executive functions the cognitive task was, the greater the productivity suffered.

Comparing cognitively healthy and cognitively impaired individuals, those with greater cognitive impairments had lower gait velocity and performed worse during the memory tasks, which is consistent with previous findings (Gillain et al., 2009; Maquet et al., 2010; Sheridan, Solomont, Kowall, & Hausdorff, 2003). Additionally, cognitively impaired individuals decreased their gait velocity more from single to dual-task than cognitively healthy, which has not yet been reported. On the other hand, the reduction of cognitive performance during the memory dual-tasks was equal to or even lower than that of the healthy group. Moreover, during the working memory dual-task, cognitively impaired individuals decreased their gait velocity more than their cognitive performance, which was contrary to cognitively healthy who decreased cognitive performance more than gait velocity. In both groups, there were no significant differences in semantic memory task performance between single and dual-task and they both decreased their gait velocity more than their cognitive performance during semantic memory dual-task. One reason for the greater reduction of working memory performance in cognitively healthy older individuals could be their higher baseline performance, which could be more susceptible to an additional motor task than the already lower single-task baseline performance of cognitively impaired individuals. Additionally, the heterogeneity of working memory task performance seems to be greater among cognitively impaired individuals. There were fewer individuals who performed worse and almost three times as many who performed even better during working memory dual-task compared to the cognitively healthy group. However, some researchers already found that individuals with a higher counting performance while walking compared to sitting also have lower scores in MMSE (Beauchet et al., 2007).

Under both dual-task conditions, cognitively impaired individuals reduced their gait velocity more than their cognitive performance and, at least during the semantic memory task, cognitively healthy individuals also reduced gait velocity more than cognitive performance. However, the difficulty of the current memory tasks was low and only with increasing difficulty of the additional tasks, a prioritization of the walking task or even a neglect of the memory task performance would have been expected (K. Z. H. Li, Lindenberger, Freund, & Baltes, 2001; Salthouse, Hambrick, Lukas, & Dell, 1996). Especially among cognitively impaired individuals, a reduction of gait velocity may allow them to maintain gait safety in the presence of an additional attention-demanding task and to have enough attentional resources to manage both tasks without having to neglect one of the tasks.

Finally, some cognitively healthy as well as cognitively impaired individuals showed improvement of gait velocity or cognitive performance or both from single to dual-task during both memory tasks. Less than two-thirds of participants decreased both velocity and cognitive performance during the working memory dual-task and less than half during the semantic memory dual-task. Some individuals predominantly reduced motor performance whereas others tended to reduce cognitive performance. This suggests that the same person could potentially be stimulated to use either one of these strategies. Instead of assuming that as individuals get older they increasingly and in a stable way tend to prioritize fall-prevention over cognitive performance, this would allow determination of the degree to which an individual may be able to do both, but triggered by the situation to prioritize one or the other. For example, this can be done by variation of cognitive task difficulty or by including obstacles like steps into the motor task. This way, our approach to determine adaptive potentials in cognitively impaired individuals could be taken a step further. This could lead to a better understanding of adaptation processes to different tasks in our everyday life including the consideration of potential dangerous situations.

There are some limitations of the current study. First of all, we did not include patients with a score of less than 16 in the MMSE, so the current findings cannot be generalized to patients with severe cognitive impairment. Additionally, the MMSE is only a screening questionnaire and has limitations detecting executive cognitive dysfunction (Juby, Tench, & Baker, 2002). Our study did not specifically investigate dual-task performance depending on executive function, which indeed could be of particular interest with regard to the working memory task, which requires executive functions (Hittmair-Delazer, Semenza, & Denes, 1994).

Due to the large sample size with its wide range of age and different states of cognitive impairment, the findings of the current study provide a good representation of dual-task performance within the population of older adults. The study is therefore best qualified to characterize motor-cognition dual-task performance in cognitively healthy as well as cognitively impaired older individuals with regard to individual differences of gait and cognitive performance change depending on different dual-task conditions. Future research could additionally investigate dual-task performance in clinical populations or in populations with different age ranges. It would be of particular interest to investigate cognitively healthy centenarians and their performance under dual-task condition. Since they are known to have less cognitive as well as physical resources, they might cope differently with a dual-task situation than younger geriatric individuals.

3.4 Study 4: The Interplay of Cognitive and Motor Functioning in Healthy Older Adults: Findings from Dual-task Studies and Suggestions for Intervention[5]

3.4.1 Introduction

Due to demographical changes in industrialized countries around the world, an increasing proportion of the population reaches late adulthood. Aging successfully, however, not only entails reaching a very old age, but also being able to live independently and to actively follow one's interests. To achieve this, it is necessary to remain "fit", both physically as well as mentally.

This paper deals with the interplay of cognitive and motor functioning in old age, focusing on two different lines of research, namely (a) dual-task studies which require participants to perform a cognitive and a motor task simultaneously, and (b) intervention studies which investigate whether increases in physical fitness also lead to improvements in cognitive performance. The literature review in the section on cognitive-motor dual tasks primarily focuses on studies which have been conducted in the Sensorimotor-Cognitive Couplings project at the Max Planck Institute for Human Development in Berlin. The interested reader is referred to Wollacott and Shumway-Cook (2002) and Schaefer, Huxhold, and Lindenberger (2006) for more comprehensive reviews of the literature. The section on intervention studies includes a newly–developed study design to be implemented by the Gerontopsychology research unit at the University of Zurich. The final section discusses some methodological problems encountered in this type of research and suggests future directions as well as potential practical implications.

[5] A similar version of this chapter has been published in "Gerontology" (Schaefer & Schumacher, 2010)

3.4.2 The simultaneous performance of cognitive and motor tasks in late adulthood

Remaining mobile and functionally independent in old age is not a trivial task, given that aging is accompanied by decline in mental (Park, Polk, Mikels, Tayler, & Marshuetz, 2001), physical and sensory abilities (Marsiske et al., 1999). Such decline leads to performance decrements in many different cognitive tasks, with fluid intellectual abilities like cognitive speed, memory, reasoning abilities and executive control tasks showing a steeper age-related decline than crystallized abilities like knowledge of vocabulary or word fluency (Baltes, 1997). In addition, seemingly automatized motor tasks like walking or keeping one's balance require more cognitive resources in late adulthood than at younger ages due to declining visual and auditory acuity and reduced muscle strength and joint flexibility. This *aging induced permeation of motor functioning with cognition* (Lindenberger, Marsiske, & Baltes, 2000) makes it particularly difficult for older adults to master situations in which a cognitive and a motor task must be performed concurrently. For example, an 80-year-old might refrain from keeping up a conversation while crossing a busy street in order to pay attention to the traffic and any potential obstacles on the way.

Dual-task studies are often interpreted in relation to the concept of "resources" (Kahneman, 1973), which can be conceptualized as general information processing abilities, like for example cognitive speed, working memory capacity, or attention span (Guttentag, 1989). Resources are expected to be limited, and when they have to be shared between two concurrent tasks, performance in one or both tasks can deteriorate. For the assessment of cognitive-motor dual-task situations with different age groups, Li K. Z. H., Krampe, and Bondar (2005) recommend using laboratory settings similar to everyday life situations, assessing single- and dual-task performances for both tasks involved, and using difficulty levels of the two component tasks which do not lead to floor or ceiling effects in the age groups under investigation. The following studies took these considerations into account. In addition, they all compared a group of healthy young adults, aged between 20 to 30 years, to a group of healthy older adults, aged between 60 to 75 years, concerning their ability to perform a cognitive and a motor task simultaneously. The central assumption was that older adults should show more pronounced performance decrements than young adults in the dual-task situation, since their motor functioning requires more attentional resources than in young adulthood. Furthermore, in situations in which neglecting the motor performance might lead to harmful consequences (e.g., a fall), older adults were predicted to prioritize their motor functioning at the expense of cognitive performance.

Lindenberger, Marsiske, and Baltes (2000) trained young (20-30), middle-aged (40-50) and old (60-70) adults to encode word lists using a particular memory strategy until each individual reached a pre-specified criterion. The motor task consisted of walking on two narrow tracks which differed in complexity (one oval track and one with a more complex path) as fast and accurately as possible. Participants were asked to encode the word lists while sitting, standing and walking on the two tracks. Walking speed and accuracy were measured under single-task conditions (walking with no concurrent tasks) and while encoding the word lists. A proportional measure for dual-task costs was used, expressing performance reductions under dual-task conditions in relation to each individual's single-task performance. In general, dual-task costs were larger with increasing age, indicating that motor tasks such as walking require increased cognitive control with advancing age. When the difficulty of the motor task was increased, performance of the concurrent cognitive task deteriorated, with greater dual-task memory loss on the complex track than on the oval track.

Using a similar combination of tasks, Li K. Z. H., Lindenberger, Freund, and Baltes (2001) also had younger and older adults walk on an oval track while encoding word lists. The authors extended the paradigm by introducing difficulty manipulations of the two tasks, as well as by offering compensation opportunities for the increased task difficulties under some conditions. In the more difficult version of the tasks, participants were asked to walk over obstacles on the track, and the inter-stimulus intervals to encode individual words were shortened. Task difficulty was adjusted individually for each participant under single-task conditions. Compensatory external aids were provided for some trials in the form of 1) a button which could be pressed to prolong encoding times and 2) a handrail which could be used while walking on the track. There were pronounced age differences in the dual-task costs for memory, with older adults showing greater losses than younger adults. For the walking task, however, losses were comparably high for both age groups. This was interpreted as an adaptive allocation of resources in the elderly, since prioritizing the motor domain in demanding dual-task situations might protect them from falls. In addition, when given a choice of which external aid to use, older adults optimized walking, whereas younger adults optimized memory performance. This pattern of adaptive resource allocation, shifting attention to the motor task when the situation becomes challenging, has also been demonstrated by children (Schaefer, Krampe, Lindenberger, & Baltes, 2008), and it seems to be preserved in older adults suffering from Alzheimers disease as well (Rapp, Krampe, & Baltes, 2006).

To investigate performance trade-offs in the domain of spatial navigation, a study by Lövdén, Schellenbach, Grossmann-Hutter, Krüger, and Lindenberger (2005) asked younger and older men to walk on a treadmill while navigating through a virtual museum projected on a screen in front of them. Their task was to reach the museum's bistro twice in a row via the shortest possible route. In order to do this, they had to explore the museum and create a mental map of the shortest route once they had found it. In some conditions, participants were allowed to use a handrail while walking on the treadmill. Younger adults' path-finding performance was superior to that of older adults. Furthermore, older men demonstrated increased body sway while walking under cognitive load as compared to walking with no navigation task, while there were no differences in body sway for younger men under either set of conditions. In addition, handrail use increased navigational performance in older but not in younger men, indicating that lowering the attentional demands of walking by providing a handrail helps older adults, who must concentrate more on the motor task.

However, cognitive-motor dual-task situations do not always lead to performance decrements. A study by Huxhold, Li, Schmiedek, and Lindenberger (2006) required younger and older adults to sway as little as possible while standing on a force plate. The dependent measure for balance performance was the area covered by the center of body pressure (COP) over time, with smaller areas representing a better balance performance (less body sway). Various cognitive tasks were assessed under single- and dual-task conditions, namely a two-choice reaction time task, a 2-back working memory task with digits, and a spatial 2-back working memory task. Participants performed the cognitive tasks while sitting on a chair (single-task condition) and while standing on the force plate (dual-task condition). There was also a condition in which participants were instructed to sway as little as possible while simply watching a series of digits presented on the screen in front of them. Cognitive performances did not differ between sitting and standing. For the balance task, older adults showed larger COP areas than younger adults, but both age groups reduced their body sway when watching digits on the screen as compared to balancing with no cognitive task. This indicates that focusing one's attention exclusively on a motor task which is usually performed automatically can lead to performance decrements. When cognitive load was increased by presenting more difficult cognitive tasks, older adults increased their body sway again. This resulted in an inverted U-shaped relationship between the efficacy of postural control and concurrent cognitive demands, and supports the notion that older adults have to invest more attention into their motor functioning than young adults, who continued to show reduced levels of body sway even when the difficulty of the concurrent cognitive task was high.

Similar findings were obtained in a study by Lövdén, Schaefer, Pohlmeyer, and Lindenberger (2008), in which younger and older adults were asked to walk on a treadmill while performing a working memory task with four difficulty levels. For the N-back task, participants were presented with a series of digits via loudspeaker. In the easiest version, N-back 1, participants were asked to compare the digit they heard to the previous one, whereas in the most difficult condition, N-back 4, they were required to compare the current digit to the one 4 back in the sequence. The regularity of their gait was measured by the variability of different spatio-temporal gait parameters such as stride length, stride time and walking velocity. Similar to the findings by Huxhold and colleagues (2006), both younger and older adults showed less gait variability when walking with an easy cognitive task, as compared to walking with no cognitive task. Younger adults decreased their gait variability further with increasing cognitive load (N-back 2 to 4), while older adults showed stability or increases of gait variability under these conditions. These findings were substantiated by Verrel, Lovden, Schellenbach, Schaefer, and Lindenberger (2009), who used a different measure of gait stability, principal component analysis, which separates regular from irregular components of whole-body motion.

Taken together, cognitive-motor dual-task studies comparing young and old adults support the assumption that older adults need to concentrate more on their motor functions, leading to more pronounced performance decrements in a dual-task situation than in young adulthood. In addition, the elderly tend to focus their attention on motor tasks in demanding dual-task situations which involve a risk to physical balance, possibly to avoid falls (Shumway-Cook & Woollacott, 2000, posture-first hypothesis).

3.4.3 The Positive Influence of Fitness Interventions on Cognitive Functioning in Late Adulthood

Fitness intervention studies also investigate the interplay of cognitive and motor functioning, with the underlying assumption that increases in physical fitness also lead to beneficial effects on cognitive functioning. As opposed to the dual-task studies investigating performance changes in both task domains, the fitness intervention studies assume that increases in motor performance (physical fitness) will increase cognitive performances, and not vice versa. In these studies, previously sedentary elderly participants take part in an exercise-training regime that enhances their aerobic fitness (e.g., via walking, swimming or cycling). The control group also exercises but follows a training regime which does not lead to increases in aerobic fitness (e.g., stretching, toning or strength training). Following the intervention, cognitive performances are compared to the baseline performances before training. Colcombe and Kramer (2003) conducted a meta-analysis based on 18 such studies of older adults. They reported impressive improvement in cognitive performance via aerobic fitness training (0.5 standard deviations on average). Benefits of aerobic fitness training were greatest for rather difficult cognitive tasks involving executive control processes, but fitness-related benefits were reliable for visuospatial tasks and tasks involving controlled processes as well. Benefits were also greater for training regimes which lasted for more than 6 months and for longer than 30 minutes in each individual training session, for those which combined aerobic and strength training, for samples which included more female than male participants, and for participants aged 66 to 70 years as compared to younger or older participants.

These results indicate that aerobic fitness training can enhance the cognitive vitality of older adults. This is supported by animal studies showing that aerobic fitness positively influences brain metabolism and neurogenesis in mice and rats (Black, Isaacs, Anderson, Alcantara, & Greenough, 1990; Fordyce & Farrar, 1991; Neeper, Gomez-Pinilla, Choi, &

Cotman, 1995; van Praag, Kemperman, & Gage, 1999), and by human brain imaging data indicating that aging-related declines of neural tissue can be counteracted by a high level of aerobic fitness (Colcombe et al., 2003; Colcombe et al., 2006). Apparently, training regimes which increase older adults' physical fitness can, at least to a certain extent, "turn back the clock" and reverse some of the negative effects of biological aging and may also lead to an increase in cognitive performance.

These findings are especially interesting in light of cognitive intervention studies with older adults, which often demonstrate impressive improvements in the trained cognitive task but little transfer to untrained tasks (see Hertzog, Kramer, Wilson, & Lindenberger, 2009, for a review). For example, old and very old adults show substantial performance improvement in remembering word lists after practicing a memory strategy to encode word lists (Baltes & Kliegl, 1992; Brehmer, Li, Muller, von Oertzen, & Lindenberger, 2007; Singer, Lindenberger, & Baltes, 2003), but their performances in other cognitive tasks do not improve reliably. It is therefore of great importance to the field of aging research to conduct studies which directly compare the effects of cognitive and aerobic fitness training in order to determine which training regime is most helpful for various kinds of cognitive performances and specific populations.

To our knowledge, there are three studies which have integrated cognitive and cardiovascular training tasks into one training for combining the positive aspects of both types of training tasks (Fabre, Chamari, Mucci, Masse-Biron, & Prefaut, 2002; O'Dwyer, 2009; Oswald, Gunzelmann, Rupprecht, & Hagen, 2006). In the study of Fabre, Chamari, Mucci, Massé-Biron, and Préfaut (2002), for example, participants aged 60 to 76 attended one or three (subject to group membership) training sessions per week over a period of two months. Participants either participated in aerobic training, memory training, combined aerobic and memory training or a passive control group. The aerobic training session consisted of 60 minutes of brisk walking and/or jogging, and memory training entailed 90 minutes of mental training conducted on the basis of the Israel's method (Israel, 1987). Participants of the aerobic training attended two training sessions per week, whereas participants of the memory training group trained only once a week. The combined training group participated in all the aerobic as well as memory training sessions. All three training groups demonstrated a significant improvement in the total score of Wechsler in contrast to the control group. Moreover, the combined training group demonstrated greater improvement of the cognitive function on the memory quotient (cf. Fabre et al., 2002) than the other two training groups.

Oswald, Gunzelmann, Rupprecht, and Hagen (2006) obtained similar results. Although their physical and cognitive training as well as the age of their participants (75 to 93 years olds as compared to 60 to 76 year olds in the Fabre et al. study) and the amount of training differed from Fabre et al. (2002), the findings were almost the same. They found that especially the combined physical and cognitive training group outperformed their counterparts in the control group over the long term. While these findings demonstrate a clear advantage of combined training in contrast to single task training, this is not the case for the results found in O'Dwyer's (2009) training study. Although the exercise group taken together with the combined exercise and cognitive training group displayed significant improvements in memory compared to the control group, the performance of the two training groups did not differ significantly. The differences in findings should not be overinterpreted due to differences in the variables investigated. The different training groups are hardly comparable with each other since the duration of the various training sessions varied considerably. In the study of Farbre et al. (2002), for example, the mental training group attended one training session per week in contrast to the physical training group and the combined training group, who attended two and three training sessions per week respectively. The Oswald et al. (2006)

training study was conducted using the same approach. However, in contrast to the Fabre et al study, the participants were required to perform the physical and cognitive training in the same training session. In O'Dwyer's (2009) study, the participants of both the exercise and the combined exercise and cognitive training groups received three training sessions per week. Whereas the exercise group attended three physical training sessions per week, the combined training group only participated in two physical training sessions with an additional cognitive training session per week. Therefore, it is not clear how strongly the different outcomes of the studies have been influenced by unequal exposure to the physical and cognitive training tasks, and the positive effect of combining both trainings cannot be separated from these unequal exposure times.

3.4.4 Design of an Intervention Study Combining Cognitive and Fitness Training in Older Adults

In order to get a clearer picture of the effects of combined cognitive and motor interventions in late adulthood, the Gerontopsychology research unit of the University of Zurich is currently planning an intervention study in which subjects participate in combined training. Both training tasks, cognitive and motor, are designed to activate the same brain region, namely the cerebellum (cf. Desmond, Gabrieli, Wagner, Ginier, & Glover, 1997; Durisko & Fiez, 2009; Jahn et al., 2004). Cognitive training consists of verbal working memory tasks, and motor training consists of treadmill walking. In the cognitive training participants are required to perform an adaptive n-back task (Buerki, Ludwig, Chicherio, & de Ribaupierre, 2009) as well as an adaptive verbal serial position task. Both of these cognitive training tasks are designed in a way that they can be performed either in single task as well as in dual task conditions. As for the motor training, participants must walk on a treadmill at a speed which will lead to improvements in cardiovascular fitness. The goal of this study is to train the oldest old. However, since the cognitive as well as the motor training are highly demanding an age limit of 85 is envisaged. In order to obtain a preferably homogenous age group an age range of ten years is defined. Participants will be randomly assigned to one of four groups: one group must perform the treadmill training sessions first and then the verbal working memory training sessions, the second group must do the verbal working memory training sessions first and then the treadmill training sessions, the third group will perform the verbal working memory training simultaneously with the treadmill training in all training sessions, while the fourth group will act as the control group (see Figure 5). In this way, it should be possible to measure the effect of the training sequence as well as the training condition, single versus dual task. While the variation of the training sequence allows identifying the effect of cognitive activation on the motor training and the other way round, the dual task condition gives insight into a new training approach (simultaneous training). It is assumed that by performing the two tasks simultaneously the brain activity of and around the cerebellum should be stronger and therefore should lead to a greater training benefit in the learned task as well as in near and far transfer tasks. To examine the effect of the different types of training on different cognitive abilities, participants will be tested before, during and after the training program with regard to the following age-sensitive variables: processing speed, working memory, executive control, episodic memory and fluid intelligence. In contrast to the previously mentioned studies (Fabre et al., 2002; O'Dwyer, 2009; Oswald et al., 2006) in this study all three training groups are exposed to the same amount of cognitive and motor training which allows a distinct differentiation between the training effects of all three training groups eliminating the confounding variable “training exposure”.

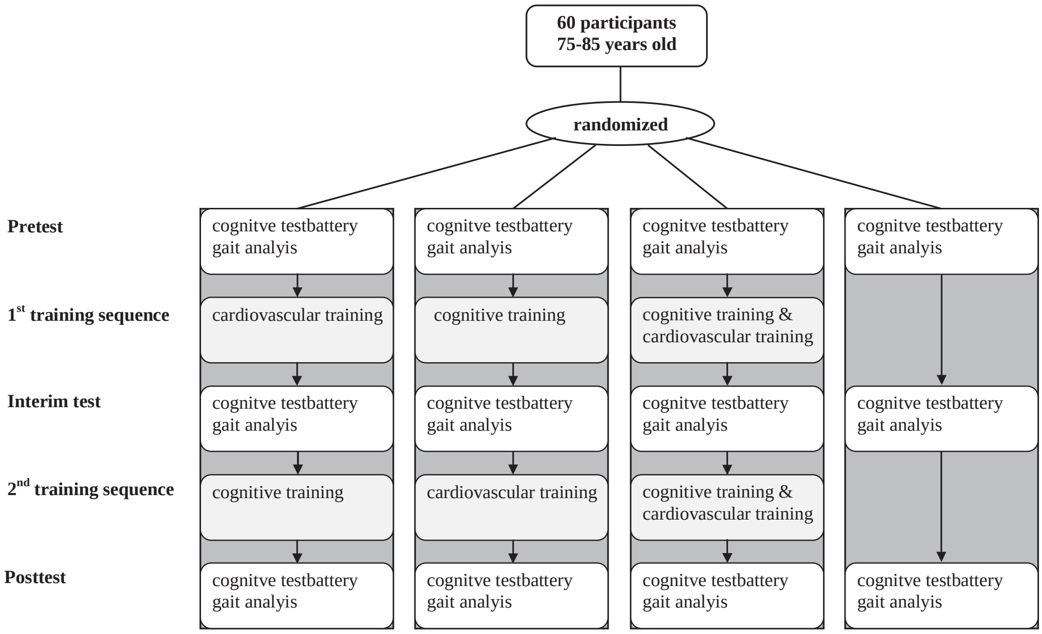

Figure 5. Model of an intervention study combining motor and cognitive training (Schumacher & Martin, 2009b).

3.4.5 Methodological Issues and Ideas for Future Research

The methodological considerations by K. Z. H. Li and colleagues (2005) concerning the assessment of cognitive-motor dual-task performances in age-comparative settings have been presented above. In the following section, we outline several methodological issues that we consider important in future intervention studies.

Concerning intervention studies that include a fitness-training regime, the fitness training should tax the cardiovascular system to the extent that aerobic fitness is likely to improve (Colcombe & Kramer, 2003), e.g. by using walking, jogging, swimming or cycling as an intervention. Heart rate should be monitored and controlled during exercise to adjust the exercise intensity of each individual. Furthermore, positive outcomes are likely to increase if participants of fitness interventions have led sedentary lives in the months and years prior to the intervention, since people who engage in regular physical activity are less likely to profit from additional training. Training regimes should be long and intense enough to lead to measurable improvements in aerobic fitness (e.g., lasting for several months, with 3 or more training sessions per week), and those fitness improvements should be documented with performances on standardized tests before and after the intervention (e.g., estimating maximum oxygen consumption while cycling to exhaustion).

If the study design includes a comparison of fitness and cognitive interventions, the specific type of cognitive training administered should fulfill several requirements to enhance transfer to other tasks. As has been shown previously, transfer is more likely to occur if task difficulties are adjusted adaptively in the course of training, and if individual feedback is offered after each trial (see Hertzog et al., 2009, for a review). Furthermore, if combined training regimes are included in the study design, i.e., if there are participants who take part in both the cognitive and the fitness training, either sequentially or simultaneously, it is important that equal time is given to both. If aerobic fitness training requires individual training sessions to last for at least half an hour in order to achieve any effect, then a cognitive training session should be given about the same amount of time. In addition, if there is a group doing both types of training simultaneously, it is of course necessary to find cognitive and motor tasks which can actually be administered that way (e.g., it is simply not possible to perform a word fluency task with verbal responses while swimming). In the same way, based on the findings from cognitive-motor dual-task research in older adults, the balance requirements of the motor task should be minimized so as not to create an additional problem for this age group. Pre- and post-test assessments including cognitive-motor dual-task situations which have not directly been trained would indicate whether the ability to perform such tasks has also been improved by the combined training and whether it can be transferred to other more or less similar task combinations. As in any study focusing on intervention effects, it is important to consider issues such as selective drop-out rates (e.g., one of the training regimes is more likely to lead to high drop-out rates) and the identification of suitable transfer tasks.

3.4.6 Conclusions and Implications for Applied Settings

We have presented two lines of evidence for a close interrelationship of cognition and motor functioning in late adulthood, namely dual-task studies combining a motor and a cognitive task, and fitness intervention studies reporting cognitive performance improvements following an aerobic fitness training in late adulthood. Older adults often show more pronounced performance decrements than younger adults in demanding cognitive-motor dual-task situations (e.g., walking on a narrow track while memorizing word lists (e.g., walking on a narrow track while memorizing word lists K. Z. H. Li et al., 2001; Lindenberger et al., 2000) and tend to protect their motor functioning by showing greater dual-task costs in the cognitive domain when balance and physical integrity are at stake (K. Z. H. Li et al., 2001; Lovden et al., 2005; Rapp et al., 2006; Shumway-Cook & Woollacott, 2000). This can be considered an adaptive behavior according to the theory of selection, optimization and compensation (K. Z. H. Li et al., 2001), since it protects from fall-related injury and harmful consequences.

In applied settings, cognitive-motor dual-task situations might be used in healthy older adults as diagnostic tools to assess limits of performance (LundinOlsson, Nyberg, & Gustafson, 1997) and to identify situations that might involve a risk to balance. However, it should be kept in mind that dual-task situations do not necessarily lead to performance decrements (Huxhold et al., 2006; Lovden et al., 2008; Verrel et al., 2009) and that there might be situations in which healthy older adults even profit from the concurrent performance of an easy cognitive task. Identifying dual-task situations which are particularly problematic or particularly advantageous for elderly individuals may be of help to those who design interventions adjusted to individual needs.

From the authors' point of view, the positive influences of aerobic fitness interventions on cognitive functioning in late adulthood have great potential for improving the lives of older adults in modern societies. In the face of physical and mental declines with advancing age, leading a more active life might help to optimize an individual's aging trajectory (Hertzog et al., 2009), by increasing not only health and physical well-being, but also by slowing down or even reversing some of the biological aspects of the aging process (Colcombe et al., 2003; Colcombe et al., 2006) and their negative consequences on cognition. This should be taken into account not only by therapists working with elderly populations but also by the interested layperson with the goal to "age gracefully". Future research should aim at elucidating the mechanisms responsible for favorable outcomes.

4 General Discussion

The following section contains a summary of the results of the four studies as well as a discussion of their relevance to the research questions presented earlier. It also describes limitations of the different study designs as well as future perspectives for the different research areas. Finally, it provides an outlook on a new research field by introducing cognitive rigidity as a new concept complementing the concept of cognitive plasticity.

4.1 Summary and Discussion of Results

4.1.1 Cognitive Development and Plasticity in the Oldest-old

The first aim of the present thesis was to analyze longitudinal studies containing cognitive data of individuals aged 80 years or older. These studies had to cover a developmental timespan of at least six years (until 2009) and two or more data waves to be included in the database. Data were gathered from the list of longitudinal studies from Hofer and Piccinin (2007) and supplemented with studies from the IALSA- and NIA-website. After screening, there were 66 studies which fulfilled the above-mentioned criteria.

Surprisingly, only seven studies from the list in chapter 3.1 focused exclusively on individuals aged 80 years or older, namely Fredericton, H85, HD 100, Lund, NECS, OCTO-Twin and SWILSO-O. Smith and Zank (2002) found similar results when looking at 32 psychological studies. Only five studies out of their meta-analysis consisted solely of subjects aged 85 years or older. The results of this thesis are in accordance with the findings of Smith and Zank (2002) and indicated that many of the international studies on adulthood have concentrated on young and middle adulthood. As mentioned in chapter 3.1, the average age of the general population is rising. This means that there are more and more individuals classified as “elderly” and that life expectancy is increasing. Despite this shift in demographics, there is a general lack of research on cognitive development in the oldest-old, especially longitudinal studies. It is important to realize that this field of research may provide valuable information on how to better serve the needs of the aging population, especially since the examination of the currently oldest-olds provides insight into the future young old due to a shift in age phases. In a more general way, it might even lead to the discovery of factors which may extend life. Even more importantly, regarding cognitive plasticity, it may help to identify factors which increase, stabilize or retard the deterioration of cognitive abilities. Such information can be obtained by analyzing individuals who demonstrate positive cognitive development and by identifying factors common to all of these individuals. Finding such factors is particularly important since a decrease of cognitive abilities in old age not only leads to a restriction of personal autonomy but also places psychological strain on the person concerned.

Although longitudinal studies open up new vistas in the research of the oldest-olds, they also pose different methodological challenges. As described earlier, there are several methodological challenges which have not yet been solved. One challenge is sample selectivity. Other aspects of selectivity are self-selectivity or selectivity through mortality. All three aspects create a bias in the results in the direction of populations examined seeming physically and cognitively healthier than in the “true” population.

A further challenge involves length of time between the various data waves. There is no standard means of defining these intervals. Often a long interval is needed when examining adaptation processes in old age. However, if the intervals chosen are too long, the researcher risks losing participants due to mortality. Since chronological age is not as predictive for developmental changes in the elderly as it is in the young, some researchers focus on the closeness to death as a predictor variable for the occurrence of certain developmental incidences. However, these are two different approaches examine different developmental process and therefore cannot be compared to each other.

The last methodological challenge of longitudinal research of the oldest-olds lies in the optimal choice of data depth and width. Especially in old age, when personal resources are limited, the choice of the test battery must be planned carefully. If too few tests are administered, there may be a lack of essential data, but if too many tests are presented, participants may become tired, causing the results to be biased. Although old age poses different methodological challenges for longitudinal research, it is clear that the findings far outweigh any problems or difficulties.

The next step would be to analyze the data of the above-mentioned longitudinal studies concerning cognitive plasticity. It is of major interest to observe how people adapt to different circumstances and contexts although their personal resources decrease with increasing age. It is possible that cognitive plasticity relies on similar mechanisms, such as subjective well-being and autonomy, which means that cognitive plasticity might be a result of the interplay between different abilities and different contexts (cf. orchestration model of Zöllig et al., 2009). This implies that cognition, especially behavioral cognitive plasticity, is perceived as a result of different systemic variables which constantly influence each other.

4.1.2 Education as protective factor against cognitive decline

The second aim of this thesis was to investigate the relationship between extremely high education together with its underlying factors and cognitive aging. Previous findings fail to provide a clear indication of whether or to what extent education affects cognitive development in old age in populations in which the level of education is representative of what can be expected in future cohorts of older adults (cf. Baltes & Lindenberger, 1988; H. Christensen et al., 1997; Hultsch et al., 1999). The second study presented in this thesis was carried out in order to fill this gap. The sample consisted of 62 retired professors of the University of Zurich and 196 participants from the ZULU-study, between the age of 65 and 80 years. Participants were tested for episodic memory, working memory and speed of processing.

The results of the first wave of the longitudinal study of professors of the University of Zurich show that the high education sample was superior to the normal education sample in two out of four tests; in paired-associates learning and reading span, respectively. However, if stratified for age, the results of the paired-associates test revealed no significant difference between the groups of 65 to 72-year-olds of the two samples. This indicates a decrease in performance for post-72 participants in the normal education sample only, which suggests that high education helps to maintain cognitive performance in paired-associates learning until the age of 80 years. Interestingly, whereas there was a negative relationship between age and performance on the paired-associates learning test for the normal education sample, the performance of the high education sample increased with increasing age, although not significantly. A further age effect was found in the letter digit task in both samples.

Surprisingly, in contrast to prior assumptions and findings of previous studies (Shimamura et al., 1995), no age effects were found in either reading span or story recall tasks in the normal education sample, which was possibly due to a particularly high performance sample. Although the absence of age effects in two (normal education sample) and three (high education sample) out of four tests might be good news with respect to cognitive development in old age, such data makes it hard to verify the hypothesis that extremely high education functions as a protective factor against cognitive decline. However, it seems that education does positively influence cognitive development for paired-associates learning in old age. The question of whether the absence of an age effect in paired-associates learning is due to a protection against or a postponement of age deficits can only be answered based on longitudinal data.

The present study demonstrates the relation between extremely high education and different cognitive abilities. The next step will be to conduct a follow-up and to analyze the data according to individual changes over time. This might help determine the influence of extremely high levels of education on the development of cognition in old age in more detail. Furthermore, by including variables such as workload in the analysis, it may be possible to differentiate between the effect of education and other stimulating environmental factors. If for example a decrease in workload relates significantly to a decrease in cognitive abilities independent of age, the explanatory variable of the absence of age effect in professors might be due to a stimulating work environment rather than education.

Concerning brain plasticity, it would be of major interest to determine whether cognitive plasticity is a consequence of education or if education is a consequence of a more plastic brain. Garlick (2002), for example, hypothesizes that individuals may vary in terms of plasticity processes. This means that individuals whose neuronal network is better able to adapt its connections to the environment can learn to read faster, accommodate information from the environment better, and score higher on an actual fluid intelligence test. These assumptions would argue to some extent that cognitive plasticity determines education. By contrast, Mazzona and Banks (2010) found that the change to the minimum school-leaving age in the United Kingdom from 14 to 15 significantly affected memory and executive functioning. Since the years of education are in this case defined by external factors, these findings indicate that education determines cognitive plasticity. Therefore, more research is needed to determine the causal direction of cognitive plasticity and stimulating factors such as education and the extent to which cognitive plasticity and these environment factors influence each other.

4.1.3 Influence of cognitive status on dual-tasking

The third aim of the thesis was to investigate dual and single task performance as a function of cognitive status. Few studies have investigated dual-task performance by comparing older adults depending on their cognitive status (Gillain et al. 2009; Maquet et al., 2010; Sheridan et al., 2003). They mainly concentrate on group differences concerning the various conditions but neglect the analysis of the change in cognitive performance between single and dual-task conditions. The third study presented in this thesis was carried out to investigate dual-task cost as a factor of cognitive status as well as the influence of the type of task on dual-task performance. This was achieved by analyzing the single and dual-task data of 711 older adults aged 65 to 97 from the Basel Memory Clinic and the Basel Study on the Elderly.

The results of the Basel cohort demonstrated that independent of cognitive status there was a tendency for the participants to decrease their gait velocity under dual-task conditions with a greater decrease under semantic memory dual-task performance. Regarding the cognitive data, performance of the semantic memory task remained stable under dual-task conditions, whereas working memory performance decreased. Concerning group differences, overall cognitively impaired participants concentrated more on the maintenance of their cognitive performance while the cognitively healthy tried to stabilize their gait velocity. This was especially true during the working memory dual-task condition. These findings which show the difference between the cognitively impaired and the cognitively healthy participants with regard to greater reduction in gait velocity have not yet been reported in other studies. Possible explanations for this prioritizing of the cognitive task over the motor task in cognitively impaired older adults could be the following: 1) it might be that through the loss of cognitive resources they have lost the ability to prioritize tasks, which means they cannot estimate the correct performance according to a change in environment or 2) it might be that in cognitively healthy older adults the higher baseline cognitive performance was more susceptible to an additional motor task. However, these data also demonstrated large individual differences. Despite cognitive status, there were some individuals who improved gait velocity or cognitive performance or both from single to dual task.

These findings are of major interest with regard to healthy cognitive aging. Although the literature has demonstrated that with increasing age the ability of dual-tasking decreases as a consequence of a decrease in personal resources (cf. Lindenberger et al., 2000), cognitively healthy individuals are normally able to adapt their behavior accurately even in old age. Since falling is a threat to a person’s health in old age, the expected behavior in a dual-task situation would be to favor the motor task rather than the cognitive. This indicates that accurate task prioritization is an indicator of cognitive health, which means that a person is cognitively healthy as long as this person can successfully adapt to increased demands of the environment.

4.1.4 Dual-task influence on cognition

The fourth aim of the thesis was to investigate the interplay of motor and cognitive functioning and to identify possible interventions resulting from these findings. For this purpose, the following section provides a summary and discussion of the literature on cognitive-motor dual-tasks studies from the Sensorimotor-Cognitive Couplings project at the Max Planck Institute for Human Development in Berlin as well as on physical and combined physical and cognitive training.

Studies investigating dual-task performance have demonstrated that, especially in old age, dual-task performance leads to an overall performance decrease. Since performance reductions under dual-task conditions in relation to each individual’s single-task performance are greater with increasing age, this indicates that motor tasks such as walking require increased cognitive control with advancing age (Lindenberger et al., 2000). Furthermore, it seems that older adults tend to favor the maintenance of motor functioning at the expense of cognitive performance, especially when loss of motor performance might have harmful consequences. One way to stabilize motor performance is by offering compensation opportunities. If participants have the chance to manually slow down the cognitive load of the task or to use a handrail while walking, their motor functioning is comparable to younger participants. However, compensation opportunities do not influence the age deficits in dual-task performance costs of the cognitive performance. These results suggest that personal resources are limited to a certain extent and cognitive performance in dual-task conditions decreases if more resources are needed to perform motor tasks due to decline in visual and auditory acuity, reduced muscle strength or joint flexibility (cf. Lindenberger et al., 2000). As previously mentioned, it is not only cognitive performance which decreases under dual-task conditions. Although dual-task performance affects motor functioning less than cognitive functioning, there is clear evidence for gait instability under dual-task performance (cf. Lovden et al., 2005). However, dual-task performance does not always lead to poorer performance in the cognitive task; under certain circumstances cognitive performance might even increase. In the case of balance maintenance where too much attention focusing might lead to instability, the simultaneous performance of a simple cognitive task enhances motor performance. Yet, if the cognitive load is increased and more resources are needed, then older participants tend to increase their body sway. These findings indicate that in old age more resources are needed for motor as well as cognitive functioning and that they are two different processes competing for the same resources.

Based on these results, three different possibilities are assumed to enhance personal resources and therefore reduce dual-task costs in old age. The first way, also the most difficult, is to increase the cognitive abilities, thus leaving more resources for motor functioning. As discussed earlier, this can be achieved through exposure to a stimulating environment or through training. However, it is questionable if exactly those abilities are enhanced which are needed for the dual-task performance. A second possibility is to enhance motor performance. This method not only leads to automatization in the trained task and, therefore, to a reduction of required resources, it also results in improvement in cognitive performance. The third possibility is to increase dual-task resources by training the dual-tasking itself. The last two possibilities will now be discussed in more detail.

Various studies have demonstrated that aerobic fitness training not only improves physical fitness, but also increases cognitive health in older adults (Colcombe et al., 2003). This can be seen in the enhancement of their physical and cognitive performance and an increase in the gray and white matter of the prefrontal and temporal cortices. Since both physical as well as cognitive base levels are increased, fewer resources are needed to improve dual-task performance. However, the effect of physical training on dual-task performance has only been investigated in the cognitive modality, meaning that the task required performance in auditory and visual cognitive discrimination. Results showed that the participants in the aerobic training group improved dual-task performance significantly (Hawkins, Kramer, & Capaldi, 1992). These findings are in accordance with the assumption that an increase in the performance of one modality, here cognition, can improve dual-task performance. Since physical training enhances both physical and cognitive performance, it might be the case that training effects on dual-task performance of two modalities (combining physical and cognitive performance) are even greater. However, further investigations are needed to confirm these assumptions.

The third way to enhance dual-task resources is to train the ability to perform two tasks simultaneously. For this purpose, we have in the meantime designed a training study which trains physical and cognitive performance simultaneously. Studies combining physical and cognitive training have already demonstrated that the integration of both physical as well as cognitive modalities influence training success significantly (Fabre et al., 2002; Oswald et al., 2006). However, as discussed earlier, this might not be an effect of the combined training. It rather seems that the positive effect of these training studies result from the independent stimulation of the physical and cognitive systems, which could also be achieved with two separate trainings. Therefore, the new approach of the training study of the Gerontopsychological Unit of the University of Zurich is to actually train both tasks simultaneously and sequentially as well as to investigate the effects of dual-task training and sequential training on physical and cognitive performance. Preliminary data of the combined training group demonstrate that older people are able to achieve impressive training gains in dual-task training combining walking and working memory. In each training session participants were asked to perform an adaptive *n*-back task for 15 minutes (Buerki et al., 2009) and an adaptive serial position task also for 15 minutes. In the serial position task, a series of words was presented followed by a distractor task. At the end, the same words were presented again. Participants then had to decide if the word order was the same as the one previously shown. Over the course of 20 training sessions, most of the participants continuously improved in either or both of the working memory tasks. They were even able to achieve a maximum of 15-back and to recognize a series of 23 words. Since the follow-up has not yet been completed, no conclusion can be drawn concerning transfer effects to other single and dual-task abilities. However, the training gains indicate that it is possible to train dual-tasking, an ability which decreases in old age. Furthermore, the combination of the physical and cognitive tasks created a highly motivating training situation. In contrast to other studies which reported that working memory training, especially n-back training, is often perceived as rather boring, our participants reported that the training was extremely motivating from beginning to end. Further results should indicate to what extent the gains in the trained task can be transferred to other motor, cognitive and dual-task abilities.

Although all of these studies try to investigate or improve physical or cognitive performance or both, the underlying processes of the interplay between physical and cognitive functioning in old age are not clearly understood. The question of whether the age effect in dual-task performance is due to a greater need for more resources or to a loss of resources cannot be answered. The same problem applies to training studies. It is not clear whether the improvement in performance is due to a more efficient utilization of resources, a gain of resources or a reduced need for resources. This demonstrates the need for more research on the concept of resources, which in turn would lead to more effective intervention studies on improving cognitive and dual-task performance.

4.2 The concept of cognitive rigidity

Although cognitive plasticity affects cognitive aging to a large extent, it cannot completely account for the flexibility of the aging brain. Closer study of the literature on cognitive plasticity shows that other concepts might influence the positive development of the aging brain. Therefore, this thesis will introduce the concept of *cognitive rigidity,* i.e., a resistance to cognitive change. However, cognitive rigidity cannot be equated with the absence of plasticity. There is an absence of plasticity, or, better said, non-plasticity, if an organism or process cannot be changed. By contrast, cognitive rigidity implies the presence of cognitive plasticity but only under specific circumstances. The results of this thesis indicate that cognitive rigidity, along with specific biological factors, is a consequence of exposure to time. In other words, the more often a strategy or a process is utilized, the more they become consolidated and the less sensitive they are to plasticity. The same is assumed concerning the synaptic structures in the brain. The more often a particular synaptic network is utilized, the less likely the synaptic formation will change. The idea of cognitive rigidity is in accordance with previous research such as by Rosenzweig and Bennett (1996), who stated that stimulation and experience are especially effective earlier in life. Since in younger years the amount of exposure to the same stimulus or the utilization of the same process is less than at the end of the life span, there is also likely to be an absence of cognitive rigidity. By analogy consider the example of water running down a hill. The longer the water takes the same path, the deeper the path becomes and the more effort is needed to force the water to shift tracks. Older individuals may seem to become more entrenched in their learned patterns and thus demonstrate more cognitive rigidity.

As an example, the effect of high education on cognitive plasticity could be explained through the absence of repetitive stimulation. Since working life is full of new and different demands, no routine can set in, in other words, no cognitive rigidity can take place. However, it could be criticized that cognitive rigidity is only another word for the negative side of cognitive plasticity and that cognitive rigidity is therefore an additional, but useless construct. Although this may be true for certain phenomena, it is not the case here since cognitive rigidity in connection with the factor of time is an extremely important aspect of cognitive development. With regard to training studies, this implies that processes and strategies which are overused require more training to overcome cognitive rigidity than newly acquired skills. This would also account for the differences in the results of the studies described earlier. One way therefore to achieve high training gains and transfer effects might be either to present stimulus material which cannot access earlier acquired strategies or processes or to train exceedingly long in order to overcome cognitive rigidity. However, although a task is trained to a person’s limit and rigidity with regard to the old process is overcome, rigidity might take place in the newly acquired skill. A further step therefore might be to study cognitive rigidity first as a construct and then to use the acquired knowledge for intervention studies in old age.

One way to measure cognitive rigidity would be to train younger and older people in a task which is known to require strategy use and then to instruct them to apply a different strategy while performing the training. After completing the training, participants would be asked to change back to the old strategy while performing the task. We would expect younger participants to maintain the new strategy while older people would switch back to the old one. With respect to cognitive rigidity, this means that aside from the training, the older participants have more often used the old strategy and the younger ones the new strategy. Therefore, cognitive rigidity appears in the older participants when they use the old strategy and in the younger participants when they use the newly acquired strategy.

Based on the concept of cognitive rigidity, different implications can be drawn with regard to cognitive plasticity. To achieve a high level of cognitive plasticity, factors enhancing cognitive rigidity must be omitted. As the studies on the effect of a stimulating environment such as education demonstrated, external stimulation can lead to cognitive plasticity. However, trainings which are conducted to artificially generate such an environment often fail to achieve long-term, broad effects. Taking into consideration the concept of cognitive rigidity, it is not only important for a person to be exposed to a stimulating environment. The environment should also involve different processes and alter the means of stimulation so as to make it impossible to achieve rigidity.

5 Conclusion

The aim of this thesis was to investigate factors positively influencing cognitive development and plasticity in healthy older adults aged 60 and older. This was achieved by analyzing previous literature in the field of cognitive development and plasticity, by collecting new data, and by presenting an outlook on possible intervention studies. Examining at longitudinal studies on cognitive health, it became obvious that there is a lack of cognitive research on the oldest-old. Although many longitudinal studies include elderly, only seven out of 66 studies mentioned in this thesis concentrated on the oldest-old. This indicates that cognitive research on developmental changes in the oldest old is clearly underrepresented in aging research. Much more research focuses on cognition and its trajectories in younger elderly. Previous findings as well as the results of this thesis indicate that education positively affects cognitive plasticity of younger elderly (until the age of 80 years). However, not all cognitive abilities are influenced by education. Abilities such as speed of processing decrease with increasing age independent of the level of education. According to the results of the present thesis, an effect of education was found in paired-associates learning. Whether this is due to immunization against or postponement of age associated deficits can only be answered with a longitudinal data collection (that is currently underway).

Another way to enhance cognitive plasticity is through training. Different trainings, cognitive as well as physical, have been shown to affect cognitive development in old age positively. One aspect of training is to increase individual resources or to make their underlying processes more efficient in order to enhance developmental reserve capacity. Since physical as well as cognitive training enhances cognitive performance, it seems reasonable to follow this new approach in training research by combining these two types of training. This would not only enhance the resources in physical and cognitive functioning but also the resources which are needed to perform these tasks simultaneously. Although these results clearly indicate the existence of cognitive plasticity, many questions remain unanswered.

One open question deals with the utilization and trajectories of cognitive resources. It is unclear if in old age individuals need more resources for the same process than in younger years, if they need the same amount of resources, but have fewer resources available, or if the efficiency of the resources has decreased with increasing age. Therefore, it is essential to investigate the development of cognitive resources in old age for a better understanding of cognitive development and possible interventions to enhance cognitive plasticity. Furthermore, it might be interesting to look at interindividual differences in the utilization of resources. Do two individuals, for example, possess the same amount of resources, but achieve other results when solving the same task? Investigating such interindividual differences resulting from the use of the same resources might bring forward the mechanism of the systemic interplay of resources. Taking brain plasticity as an example, it might be possible that differences in the efficiency of cognitive processes can lead to different cognitive plasticity although the same network system has been used. Such findings would indicate that there is a specific individual predisposition to cognitive plasticity.

In summary, all these findings support the existence of cognitive plasticity. However as mentioned earlier, for a better understanding of cognitive plasticity it is important to consider further concepts such as cognitive rigidity. Cognitive rigidity complements cognitive plasticity in that it views time as a crucial factor when looking at cognitive plasticity in old age. Furthermore, it provides important aspects for intervention studies. Time will tell if the currently-existing concept of cognitive plasticity remains unchanged or if it will be complemented with further concepts such as cognitive rigidity.

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